

**GROUND WATER QUALITY AND SOIL FORMATION  
IN  
WEATHERED DECCAN TRAPS OF MALWA PLATEAU, M.P., INDIA**

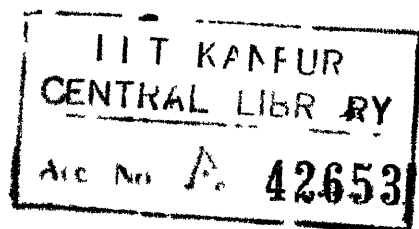
**A Thesis Submitted  
In Partial Fulfilment of the Requirements  
for the Degree of  
MASTER OF TECHNOLOGY**

***by*  
SHRENIK KUMAR LUNKAD**

**to the**

**DEPARTMENT OF CIVIL ENGINEERING  
INDIAN INSTITUTE OF TECHNOLOGY KANPUR  
MAY, 1975**

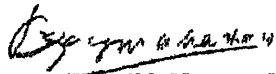
CE-1975-M-LUN-G



25 JUN 1975

CERTIFICATE

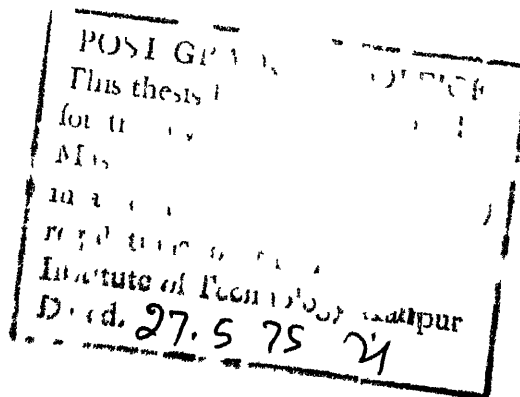
This is to certify that the present work titled, "GROUND WATER CHEMISTRY AND SOIL FORMATION IN WEATHERED DECCAN TRAPS OF MALWA PLATEAU, M.P." has been carried out by Shri S.K. Lunkad under my supervision and the same has not been submitted elsewhere for a degree.



(B.C. RAYMAHASHAY )

Assistant Professor

Department of Civil Engineering  
Indian Institute of Technology, Kanpur



### ACKNOWLEDGEMENTS

I acknowledge with a feeling of gratitude , the prompt and excellent guidance extended to me by my thesis supervisor, Dr. B.C. Raymahashay . The sincerity of his approach has been a source of constant encouragement to me throughout the completion of this project.

I am grateful to Dr. Yudhbir for his help and interest in my work and to Dr M.R. Madhav for his assistance in the Soil Mechanics Laboratory. They are also responsible for initiating my interest in the A, B, C, ... of soil mechanics. To Dr. S.K

To Dr. S K. Babu, Reader in Applied Geology, University of Sagar, M.P., I express my heartiest thanks for providing an unpublished geological base map.

I also wish to thank Dr. K V.G.K. Gokhale, Dr. D.M. Rao, and the D.T.A. machine, for the mutual co-operation between them culminated in a successful completion of my thesis.

To my following friends, for their respective contributions, I am indebted. Mr. A.G. Menon for his Pacific calmness made me forget major troubles in the Env. Engg. Lab. , Mr. D.D. Kutte for his sleepless nights and long, continuous, relevant & colloidal discussions of coagulating nature, Mr. K.N. Dey ( Ph.D. , Remote Sensing ) for sensing my troubles from remote and Mr. Som Prakash for sharing my emotions during critical hours and thus wasting my time.

Lastly, to the Institute employees Mr. M.L. Shrivastava and Mr. Vishram, ( Engg. Geol ), Mr. Gulab ( Soil Mechanics ) and Mr. S.N. Mishra ( Env. Engg. ) I record my sincere thanks for their friendly co-operation.

S.K. LUNKAD

## CONTENTS

	Page No.
LIST OF TABLES	V
LIST OF FIGURES	VI
LIST OF PLATES	VII
ABSTRACT	VIII
CHAPTER I : INTRODUCTION AND OBJECTIVE	1
CHAPTER II : LITERATURE SURVEY	8
CHAPTER III : FIELD WORK AND ANALYTICAL PROCEDURE	25
CHAPTER IV : RESULTS AND DISCUSSIONS	31
CHAPTER V : CONCLUSIONS	47
REFERENCES :	50

LIST OF TABLES

Table No.	Title	Page
1.	Chemical Composition of Deccan Basalts .	13
2.	Chemical Composition of Deccan Trap Soils .	21
3.	Location of Water and Soil Samples .	27
4.	Result of X- Ray diffraction on Fresh and Weathered Basalt.	32
5.	Modal composition of 5th flow Basalt Around Sagar .	33
7.	Results of tests for engineering index properties on Trap Soils.	37
8.	Results of Chemical Analyses of Ground Water Samples. ( in mg/litre. )	39
9.	Results of Chemical Analyses of Ground Water Samples. ( in meles/ litre ).	40
10.	Seasonal Change of Water Quality.	41
11.	Relative Geochemical Mobility of the Elements.	45
6.	Grain Size Analysis of Deccan Trap Soils	35

LIST OF FIGURES

Figure No.	Title	Following Page
1.	Sketch map showing distribution of the Deccan Traps .	1
2.	Geological map of the area around Sagar.	26
3.	Differential thermograms of black soils.	34
4.	Differential thermograms of black soils.	34
5.	Differential thermograms of red and brown ( Latent ) soils .	34
6.	X- Ray diffraction patterns of the Trap soils.	34
7.	Grain Size analysis of Trap soils.	35
8.	A- line plot of the Trap soils.	36
9.	Bar diagram showing seasonal change of water quality.	38
10.	Bar diagram showing seasonal change of water quality.	38
11.	Equilibrium diagram ( K - System ) .	42
12.	Equilibrium diagram ( Na- System ).	42
13.	Equilibrium diagram ( Ca- System ).	42

LIST OF PLATES

Plate No.	Title	Page No.
1.	Spheroidal weathering in Traps A far advanced Stage .	Frontpiece
2.	Typical flat-topped hills of the Deccan Traps.	2
3.	Rounded boulders of 6th flow Basalt around Sagar .	3
4.	A profile of black-soil around Sagar , University Campus.	26
5.	Rectangular joints in Traps and development of incipient spheroidal weathering .	3
6.	Contact between 9th and 8th flow around Sagar.	11

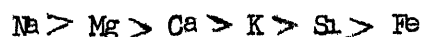


ABSTRACT

Samples from the weathered profile of the Deccan basalt outcrops in the Malwa Plateau, Madhya Pradesh, were studied along with well and spring waters contained in the same rocks with a view to deciphering the geochemistry of soil formation. Calcium rich feldspar (bytownite-anorthite), pyroxene of the augite type and volcanic glass have weathered to typical montmorillonite rich black soils with lime concretions in the poorly drained foot-hills. The soils are classified as Ch- MH according to the Unified soil classification system. Better drainage conditions on the hill-tops and the hill-slopes have given rise to iron-oxide rich lateritic soils with poorly developed clayminerals and are typified by higher specific gravity, higher shrinkage limit, lower liquid limit and plasticity index (CL-ML).

The ground water chemistry reflects strong control of rock-water equilibrium. The silica level is above the quartz and generally below saturation with amorphous silica. The  $\text{Ca}^{++} \times \text{CO}_3^{--}$  activity product is close to the saturation with calcite. Consideration of the thermodynamic fields of stability shows that the waters have reached equilibrium with kaolinite - montmorillonite assemblage and would aggressively alter the primary feldspar mineral and dissolve silica from the volcanic glass.

The relative geochemical mobility of the major cations in the Trap weathering has been found to be :



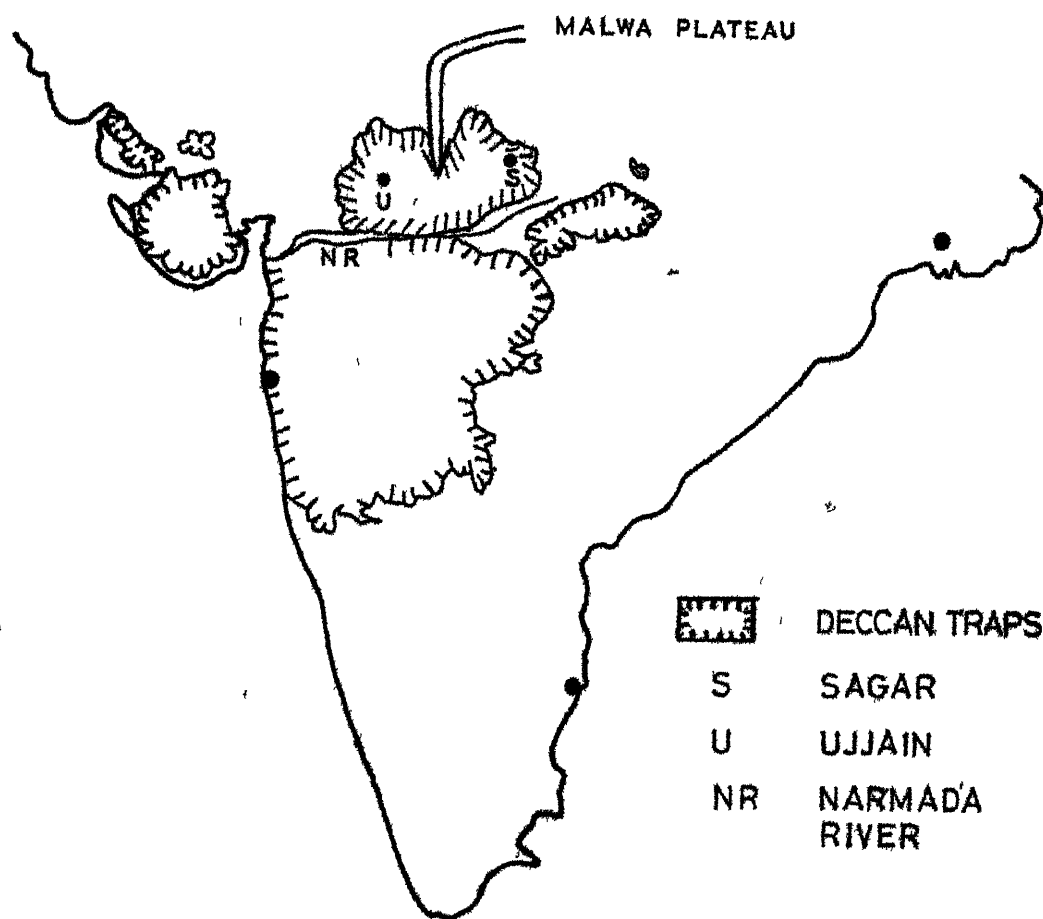


FIG.1. SKETCH MAP SHOWING DISTRIBUTION OF THE DECCAN TRAPS

## CHAPTER- I

### INTRODUCTION AND OBJECTIVE

#### 1.1 Malwa Plateau Location and Climate.

The Malwa Plateau is located on the northern-most boundary of the Deccan Trap province, separated from the rest of the area by the Narmada valley (Fig.1). It extends between latitudes  $21^{\circ}$  N and  $25^{\circ}$  N and longitudes  $74^{\circ}$  E and  $79^{\circ}$  E. The average altitude of the plains is around 400 m. and those of the hills reaching around 650-700 m. above mean sea level.

The entire plateau experiences a tropical-monsoonic type climate. Three seasons can be made out in the year, the winter (Nov. - Feb.), the summer ( March - June ) and the rainy season ( end of June-Oct. ). During summer the temperature ranges from  $25^{\circ}$  C in March to  $41^{\circ}$  C in May. The minimum temperature during winter is  $0^{\circ}$  C to  $-2^{\circ}$  C; December and January being the coldest months. The average annual precipitation ranges from 70 to 100 cms. in the west and 100 to 120 cms in the east. July and August are the rainiest months receiving about 50 % of the total annual precipitation. Relative humidity ranges from 20 to 40 % in winter and 10 to 15 % in summer.

## 1.2 Eruption of Deccan Traps

In Indian geology the Cretaceous-Eocene period ( 100 to 60 m.y. before present ) was marked by the eruption of a thick series of lava flows of basaltic composition occupying extensive areas of about 520,000 square kilometers in western and central India (Fig. 1) . This great system of volcanic rocks is known as 'Deccan Traps' because of the 'step-like', 'stair-like' or terraced appearance of the weathered flat-topped hills (plate 2), the word 'Trap' being of Swedish origin. Differential weathering and erosion has been at work on them since Eocene, removing basalts at places and laying bare the underlying older rocks. Thus a number of detached outliers occur, which are separated from the main mass by wide distances (fig. 1). The present distribution of Traps, therefore, is not the true representative of their past extension which has been calculated to have been over 1.5 million square kilometres including the segment foundered in the Arabian sea.

Based on a number of spectacular evidences, such as the total absence of any traces of volcanoes of the usual 'cone-and-crater' type, and perfect horizontality of the lava-flows, it is postulated that the eruption took place from long and narrow fissures created by

tension in the earths crust. However, a few localised instances of 'central' type of eruption have been reported such as from Girnar hills and Amba Dongar in Gujrat and near Bombay in Maharashtra, showing differentiated rocks of varying characters (Krishnan 1968). From the field and petrographic criteria the lava flows appear to have been erupted sub-aerially.

### 1.3 Weathering of the Traps and Soil Formation.

The Deccan Traps weather with characteristic spheroidal exfoliation producing rounded boulders of varying sizes on the outcrops (plate 1 and 3). The weathering starts along the joints and proceeds first rounding off the edges and corners ( plate 5 ) and then producing thin concentric shells or layers which crumble and fall off gradually. The interiors of the spheroidal masses are, however, quite fresh (plate 4 ).

The traps give rise to either a deep brown to reddish soil or to a black soil known variously as 'black-cotton soil', 'cotton-soil' or 'regur', which is similar to Russian 'chernozem'. The 'regur' is rich in plant nutrients such as lime, magnesia, iron and alkalies. It has the property of swelling greatly and becoming very sticky when wet. On drying, it contracts again becoming

very hard and stiff and developing numerous polygonal cracks. It appears to be prevalent in areas with rather low rainfall ( 50 to 80 cms annual ) and its swelling property is attributed to the high content of montmorillonite and beidellite group of clay minerals . Another product of weathering is either a 'laterite' or a 'lateritic soil', a material rich in sesquioxides, manganese and titanium and from which silica, alkalis, and alkaline earths have been leached away. Laterites highly enriched in alumina and relatively poor in iron, grade into bauxites. Laterite cappings are present in M.P. (including Malwa Plateau ) Maharashtra and elsewhere in the Deccan Trap. At places, such as on the Amarkantak Plateau in M.P., good ore deposits of bauxite have developed.

#### 1.4 Ground Water Occurrence and Quality

Ground water in Deccan Trap occurs mainly in the permeable zones at and near the contacts between different layers and in the vesicular, weathered, and fractured parts of the flows. The primary porosity is in the form of vesicles (small gas cavities ), flow contacts, lava tubes, pipes and lava tunnels. Secondary porosity is developed due to fracturing both due to cooling and tectonic reasons and weathering. From the view point of ground

water hydrology, the Traps are in general poor aquifers, being, in most of the cases, aquicludes and aquitards. Ground water occurs mostly under unconfined but sometimes under confined and 'perched-water-table' conditions. Water table in Deccan Trap plains is generally flat to gently sloping. Bulk of the ground water in Traps is drawn from shallow dug-wells or 'open-wells'. During the post monsoon months, the water table is almost near the surface. Depth to water in pre-monsoon dry months generally ranges from 4 to 15 metres.

There is hardly any published data available on the quality of ground water in the Traps of the Malwa Plateau region and very little is known from elsewhere in the Trap province in this respect. Deshmukh and Karanth, (1973) have mentioned that ground waters in the Precambrian Sedimentary and Deccan Trap province of South India are similar to those of the Precambrian crystalline province east of western Ghats. The water in the latter has been described to be slightly to moderately mineralised and neutral to slightly alkaline (pH 7 to 8 ). The dissolved solids being in the range of 3 to 10 meq/l (300 to 1000 ppm TDS), Chlorides 50 to 200 ppm and hardness 200 to 400 ppm. Dharanendran and Nagaraja(1969) reported analyses of 8 samples of groundwater from Deccan

Traps of Belgaum district in Mysore. The dissolved solids (TDS) range from 285 to 513 ppm, chlorides ( $\text{Cl}^-$ ) ranges from 12 to 56 ppm, total hardness ( as  $\text{CaCO}_3$  ) ranges from 244 to 327 ppm and sulphate( $\text{SO}_4^{=}$ ) ranges from 12 to 45 ppm. Iron, aluminium and nitrate all range from zero to less than 1 ppm.

#### 1.5 Objective of present Study

During past decade there has been a tremendous increase in our knowledge about stability of minerals in low temperature aqueous solutions. It has now become possible to predict the parameters to be expected in some of the simple rock-water systems. Recent experimental studies have lead to the recognition of the fact that the most important single control on quality of unpolluted water should be the mineralogy of the material ( rock and soil) in contact with water

With these points in view the present study was undertaken to.-

- (1) establish the nature of weathering by a systematic identifications of minerals developed in soil profiles over Deccan basalts.
- (2) evaluate the chemical quality of ground water in the same profile establishing seasonal variation, if any.



- (3) interpret the environment of soil formation in terms of mineral-water reactions.
- (4) correlate engineering properties of soils and ground water quality with mineralogy of host rocks.

## CHAPTER-II

### LITERATURE SURVEY


#### 2.1 Deccan Traps.

##### 2.1.1 Thickness and Structural Features

There is a rapid decrease in the thickness of the basalt pile from west to east. The thicknesses reported by Wadia (1960) are 650-800 m. towards Southern limit; 800 m. in Kutch; 160 m. towards Eastern limit (Amarkantak), and 30-65 m. towards Northern limit. The individual flows are about 5 m. thick on an average, varying greatly from less than a metre to about 70 m. In rare cases a single flow can reach a thickness of 65 to 90 m. (Lunkad, 1971), this being the case with the lowermost flows which are resting directly on the undulating pre-trappean topography. Around Sagar and elsewhere on the Malwa plateau, individual flows range in thickness from 10 to 30 m.

Irregular, rectangular and columnar joint systems are observed within the Traps (plate 5,7). The following table shows the general stratigraphy of the Traps

	Nummulitics of Surat and Broach; Eocene of Kutch; laterite
Unconformity	~~~~~
Upper Traps (450 m)	Of Bombay and Kathiawar; with numerous fossiliferous intertrappean beds and layers of volcanic ash
Middle Traps (1200 m)	Of Malwa Plateau, Madhya Bharat (Now Northern M.P.); with numerous ash beds in the upper portion and practically devoid of intertrappeans.

Lower Traps (150 m)	Central Province (now in M.P. South of Narmada and adjoining districts of Maharashtra) and Eastern areas with intertrappeans but rare ash-beds.
Slight Disformity	 Infra-trappean Lameta and Bagh beds; Jabalpur beds Vindhya and other rocks.

Normally, the Eastern extension of the Traps ( 100-200 m) is considered to represent the lower horizon while the upper Traps are exposed along the west coast.

#### 2.1.2 Intertrappeans, Red-boles and Ash-beds.

In upper and lower Traps, at short intervals, the lava-flows are separated by fossiliferous sedimentary beds of small vertical as well as horizontal extent, lacustrine or fluviatile in origin, deposited on the irregularities of the surface during the time interval inbetween two flows. Usually they are 1 to 3 metres thick, and not more than 3 to 4 miles in lateral extent. Lithologically, the rock varies from a black chert to buff, pink or white impure limestone and clay. Many plant remains, fresh-water molluscan shells, remains of crustaceans and amphibians are found in them as fossils ( Wadia 1966, pp. 299-300 ).

At places red coloured clayey formations, (red-boles), often brecciated containing fragments of the Trap, not more than 1 m in thickness, occur inbetween two flow units. They are of common occurrence in pink zeolitic basalts of Central Maharashtra, where intertrappeans are paractically

absent (Singhal, 1973). They are not so common in normal grey basalts.

### 2.1.3 Petrology and Petrography

The Deccan Trap belongs to the type called "plateau basalts" (Washington 1922). Petrologically they are basalt or dolerite with an average specific gravity of 2.9. They are generally dark grey, dark greenish-grey, totally black (such as flow No.5 around Sagar), and less commonly brown to purplish in colour. The rock persists quite undifferentiated in composition throughout the extent of the Traps. The only variation is in the colour and the texture. In parts of Western India including Gujrat and Kutch, localised examples of association of Traps with more acid, intermediate, basic and ultrabasic differentiates have been reported by many workers (Krishnan, 1926, West, 1958, and Chatterjee, 1961). The non vesicular flows are hard, tough and compact, whereas the vesicular ones are comparatively softer and break more easily.

The basaltic traps typically have a porphyritic texture with phenocrysts of calcium plagioclase and, less frequently of Augite type pyroxene in a matrix containing finegrained plagioclase, augite and partly devitrified glass. Magnetite is commonly disseminated throughout the ground mass. The dolerite types of traps have ophitic textures with laths of plagioclase enclosed partly in augite crystals.

The glass in ordinary grey or green basalts is almost entirely devitrified. But the black, dense varieties contain large quantities of green or brown glass, often corroded and with dust-like inclusions of magnetite.

The rock is generally free from olivine, although West (1958) has described local occurrences of basalts containing phenocrysts of plagioclase, pyroxene and olivine ("three-phenocryst-basalts").

Microscopic characters of the basaltic flows around Sagar have been described by Subramanyan (1973).

#### 2.1.4 Secondary Minerals in Deccan Traps

Secondary minerals occur either as fillings in the amygdular cavities, usually towards the top of an individual flow, or as products of alteration and replacement. Such zones of secondary minerals serve to differentiate and demarcate one flow from the other, e.g., around Sagar contact between flow 9th and 8th is demarcated by a zone of weathered pink zeolite and green-earth minerals (plate 6). The secondary minerals of hydrothermal origin are zeolites, calcite, chalcedony, opal & quartz, amethyst. Among the zeolites, stilbite is quite common occurring as radiating and sheaf-like aggregates. The alteration products are chlorophaeite, palagonite, celadonite, iddingsite and serpentine, the last two formed from olivine and the rest presumably from the glass. Several of these are called as

'Green earth' collectively, which is used as a pigment.

#### 2.1.5 Chemical Characters

Pioneering work towards the study of chemistry of Deccan Traps was done by Washington (1922), who analysed eleven samples collected from widely scattered locations. He found remarkable uniformity in the majority of the basalts with variation in silica from 48.6 to 52 %. However, the diversity in trap rock was later realised by many workers along the Narmada valley and West coast belt (Mathur et al, 1934; Crookshank, 1936; West, 1958, Sukheswala and Poldervart, 1958; and Chatterjee, 1964). The existing literature on Deccan Traps has been critically reviewed by Bose (1972) who has given the available reliable chemical analyses and normative compositions of Upper, Middle and Lower Traps and some of the distinctive petrographic types found in them.

The scope of this thesis is limited to the Traps of Malwa Plateau. These comprise only lower and middle Traps, and their composition is given in the following table. Washington's classic analyses and Upper Traps have been included in the table merely to facilitate comparison.

Table No. 1  
Chemical Composition of Deccan Basalts

	1*	2**	3**	4**	5**
SiO <sub>2</sub>	50.61	52.55	52.65	50.51	52.22
TiO <sub>2</sub>		2.56	1.70	2.85	2.15
Al <sub>2</sub> O <sub>3</sub>	13.58	13.89	14.42	12.65	13.70
Fe <sub>2</sub> O <sub>3</sub>	3.19	2.25	2.76	3.12	2.76
FeO	9.92	8.84	10.02	11.23	10.80
MgO	5.46	5.43	4.98	5.48	5.18
MnO	0.16	-	0.14	0.23	-
CaO	9.45	9.93	8.96	10.57	9.41
Na <sub>2</sub> O	2.60	2.47	3.01	2.48	2.39
K <sub>2</sub> O	0.72	1.52	1.08	0.61	0.51
P <sub>2</sub> O <sub>5</sub>	0.39	-	0.28	0.35	-
H <sub>2</sub> O	2.13	2.38	-	-	2.85
	100.12	99.44	101.00	100.05	100.97
q <sub>z</sub>	4.14	3.90	2.49	3.60	3.80
or	4.45	9.45	6.38	3.88	2.78
ab	22.01	20.96	25.66	20.43	20.17
an	23.07	22.06	22.38	21.68	25.02
ne	-	-	-	-	-
di	17.41	22.29	16.92	23.69	18.17
hy	17.78	12.84	17.72	15.59	17.84
ol	-	-	-	-	-
mt	4.64	3.25	4.17	4.41	4.17
il	3.65	4.84	3.04	5.47	4.10
ap	1.01	-	0.67	0.91	-

1\*. Average of 11 analyses by Washington (1922), from Wadia (1966), 297-298.

2\*\*, 3\*\*, 4\*\*, 5\*\*. All from Bose, M.K. (1972); (2), Average composition of upper Deccan Basalts, class A analyses (Sukheswala and Polder Vaart 1958); (3), Average composition of middle Deccan basalts. Original data (Karkare 1965); (4), Average composition of lower Deccan basalts, class A analyses, (Sukheswala and Polder Vaart 1958); (5), Average composition of lower Deccan basalt. Original data from Karkare (1965) corrected for standard oxidation.

## 2.2 The Processes of Weathering and Soil Formation

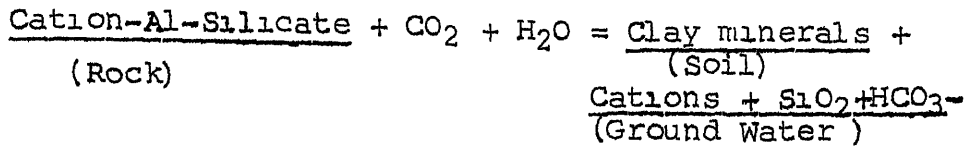
### 2.2.1 General.

There are generally two recognised groups of weathering processes, namely, mechanical and chemical. The former goes with the disintegration or crumbling up of the rock with little or no chemical change in the parent material whereas in the latter decomposition of the parent material takes place, new minerals are formed in the residue and some of the constituents are dissolved and carried away in solution. Quite often the two processes go hand in hand, now one and now the other being predominant depending on climate, topography, lithology and vegetation. Mechanical weathering is accomplished by alternate freeze and thaw, heating and cooling, mechanical action of organisms and impact of rain drops and lightning etc., while chemical weathering involves mainly the processes of carbonation, oxidation and hydration (Miller 1948).

It is chemical weathering which is responsible for the bulk of the dissolved constituents in ground waters. The generally held basic concept is of a progressive attack of water saturated with  $\text{CO}_2$  on the rock minerals. Rain water coming through the atmosphere dissolves  $\text{CO}_2$ . This is further enriched in soil profiles by  $\text{CO}_2$  derived from decaying vegetation and general increase of pressure with depth. Initial reaction by solution rich in  $\text{CO}_2$  produces kaolinite which is followed by montmorillonite as  $\text{CO}_2$  is used up and pH,  $\text{SiO}_2$ ,  $\text{HCO}_3^-$  and cation concentration rise (Garrels 1967).



The reaction in its most general form can be written as



The above reaction suggests that the  $\text{HCO}_3^-$  content (alkalinity) of natural water is a function of the extent to which the above reaction has taken place. The nature and amount of cations that are released into the ground water logically depends upon the composition of the original minerals which in turn depends on the rock type.

#### 2.2.2 Equilibrium Diagrams.

The elucidation of the principles behind the construction of equilibrium diagrams and their potential applicability to geochemical studies must be attributed to Garrels (1965). The use of these diagrams as an approach to the understanding of water-soil relationship has been demonstrated by Feth, Roberson and Polzer (1964).

Quantitative approach towards the understanding of the chemistry of ground water, by considering thermodynamic stability fields of the mineral was brought in by Garrels and Christ (1965). They expressed common weathering reactions like alteration of feldspar to mica, mica to kaolinite or Gibbsite in terms of silica, potassium ( or sodium ) and hydrogen ion concentration (pH) of the aqueous medium in which these reactions come to equilibrium and plotted the ratio  $\text{Na}^+ / \text{H}^+$  or  $\text{K}^+ / \text{H}^+$  versus silica on log-log plots. It was

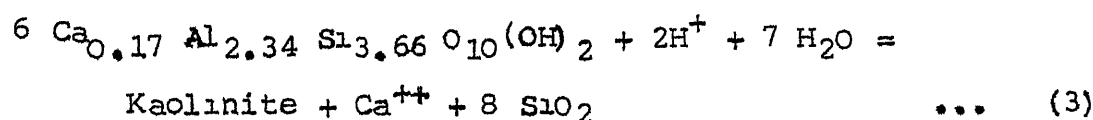
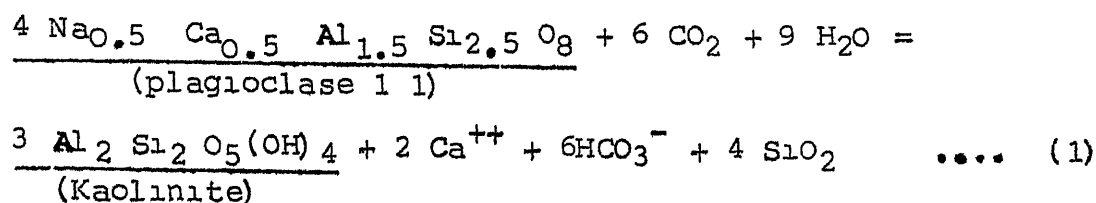
found that most ground waters fall within the Kaolinite field of stability and between Quartz and amorphous silica saturation level.

Raymahashay and Yudhbir (1973) plotted Deccan Trap water from Belgaum district of Karnataka in similar diagram and found that it plots close to the Na-Feldspar-Na-Montmorillonite-Kaolinite tripple point. These minerals are common weathering products of felspathic rocks and basalts.

### 2.2.3 Kaolinite-Montmorillonite-Illite Equilibrium:

Harris and Adams (1966) plotted surface and ground water analyses from limited drainage basins in granitic terrain of Oklahoma and Georgia on equilibrium diagrams and found that the natural surface waters of east-central Georgia were in equilibrium with Kaolinite, the major clay mineral in the soil. In contrast, the water samples of Oklahoma were in equilibrium with Kaolinite and Montmorillonite but not Illite, a major constituent of the Oklahoma soils. Thus a disequilibrium relationship between Oklahoma soils and co-existing natural waters was suggested. This theoretical evidence was further confirmed by field observations which indicated that Georgia soils were mature as compared to immature Oklahoma soils which are presently undergoing active alteration.

In order to predict the required solution characteristics, an approximation was used by Garrels (1967) by writing the reactions to form idealized Kaolinite and Montmorillonite from original plagioclase feldspar. Thus



Writing the equilibrium constant for the last reaction, we get:-

$$\log a \text{ Ca}^{++} + 8 \log a \text{ SiO}_2 + 2\text{pH} = \text{Constant}$$

On plotting  $\log a \text{ Ca}^{++} + 8 \log a \text{ SiO}_2 + 2 \text{ pH}$  versus  $\text{HCO}_3^-$  (ppm) it was found that the function chosen becomes constant at  $\text{HCO}_3^-$  concentration above 100 ppm. Therefore, the waters which are low in  $\text{HCO}_3^-$  (high in  $\text{CO}_2$ ) are busy Kaolinizing the rocks while those with high  $\text{HCO}_3^-$  are forming Montmorillonite from Kaolinite.

It has also been established by a number of workers (Grim 1968; Valetton 1972) that drainage conditions play an important role in the formation of particular clay minerals. Under freely draining conditions Kaolinite

results where as under water-logged conditions (high regional or local water-table conditions) Montmorillonite forms. This especially is the case with basic igneous rocks from which Mg is released into solution, and this, if not leached away, reacts with Kaolinite to form Montmorillonite. Mitchell (1955) studied some Scottish soil profiles found that this effect of soil drainage was more pronounced in soils on basic rocks than in soils on granitic and sedimentary rocks. He observed that in the same profile Kaolinite increased towards the upper freely drained zone whereas Montmorillonite and Illite increased towards the base.

#### 2.2.4 Equilibrium with Calcite and Dolomite.

Garrels (1967) on plotting the logarithm of the product of the concentration of  $\text{Ca}^{++}$  and calculated concentration of  $\text{CO}_3^{--}$  against  $\text{HCO}_3^-$  (ppm), found that the product becomes nearly constant at about 200 ppm  $\text{HCO}_3^-$ , suggesting saturation with Calcite. Based on  $\text{C}^{14}$  concentrations in the aquifers of Central Florida, Black, Hanshaw and Rubin (1967) reported that about 10,000 and 15,000 years of residence time is required for the ground water to become oversaturated with respect to Calcite and Dolomite respectively.

#### 2.2.5 General quality of Ground Water from Igneous Rocks:

Le Grand (1958) studied ground water of Southern Appalachians, North California and reported:-

(1) that ground water in granitic igneous rocks is characterised by low concentration of T.D.S., low hardness,

pH less than 7, about equal amount of Na and Ca and considerable percentage of silica.

(2) that ground water associated with basaltic rocks is typified by a higher concentration of T.D.S., greater hardness, pH greater than 7, a greater amount of Calcium than Sodium and a concentration of Silica that is comparable in amount but much lower in percentage than in other water.

(3) that a prolonged contact with rocks and an increased depth of circulation cause increase in T.D.S. but there is no direct effect on T.D.S. of the rate of circulation, topography and climate.

Studies by Garrels and his co-workers lead to following generalizations -

(1) waters from felspathic igneous rocks are mainly  $\text{Na}^+$ ,  $\text{Ca}^{++}$ ,  $\text{HCO}_3^-$  waters rich in Silica.

(2) the usual high percentage of plagioclase relative to dark minerals leads to the high percentage of  $\text{Na}^+$  and  $\text{Ca}^{++}$  in water. Silica is derived almost entirely from plagioclase and mafic minerals, a little comes from K-Felspar and almost none from Quartz.  $\text{K}^+$  and  $\text{Mg}^{++}$  probably come chiefly from lotite, Hornblend or Augite.  $\text{HCO}_3^-$  is the dominant anion;  $\text{Cl}^-$  and  $\text{SO}_4^{--}$  are commonly contaminants from rain water.  $\text{Cl}^-$  may also be derived from fluid inclusions and  $\text{SO}_4^{--}$  from Anhydrite and Pyrite.

(3) plagioclase felspar and mafic minerals are attacked much more rapidly than K-felspar and Quartz which

are relatively inert. Kaolinite is the chief alteration product along with other minerals such as Montmorillonite, Chlorite, Illite and Oxides and hydroxides of Fe and Al. In many cases alteration products are X-ray amorphous or composed of a complex of poorly defined aluminosilicates.

#### 2.2.6 Mobility of Elements in Weathering Cycle.

Mobility is defined as the comparative rate at which an element moves from its source in the parent rock to the stable aquatic environment and is given by -

$$\frac{\% \text{ of the element in water}}{\% \text{ of the element in rock}}$$

The following general estimates of the order of mobility of the common elements were computed by Feth, Roberson and Polzer (1964) -

$$\text{Ca} > \text{Na} > \text{Mg} > \text{K} > \text{Si} > \text{Al} = \text{Fe}$$

Anderson and Hawkes (1958) obtained similar ratios from analyses of waters and rocks from three individual local drainage basins within which the order of mobility is as follows:

$$\text{Mg} > \text{Ca} > \text{Na} > \text{K} > \text{Si} > \text{Al} = \text{Fe}$$

### 2.3 Engineering Characteristics of Trap Soils:

#### 2.3.1 Black Cotton Soils:

Black cotton soils are clayey (Banerjee 1970, and Katti 1966) and derive their dark colour from the clay-humus complex (Gananathan 1967; Singh 1954). The black colour

can be changed to red, reddish-brown, or yellowish by oxidising the organic matter by treatment first with HCl (to decompose carbonates) and then with  $H_2O_2$  (Singh 1954).

Poor engineering behaviour of black soils has been attributed to their high plasticity, low shrinkage limit and high swelling characteristics, due to which the stability of the structures built on them is adversely affected. Roy and Das (1952, as quoted by Simonson 1954) and Banerjee (1970) reported Montmorillonite as dominant clay mineral in black cotton soil from Indore (Western Malwa Plateau). The former also reported Illite and Kaolinite in appreciable quantities. Montmorillonite group of minerals have been identified in the clay fraction of a black cotton soil from Hyderabad (Simonson 1954). The coarse clay fraction of the same soil contains Kaolinite. The clay fraction (0.06 to 0.1 micron), which comprised about 40% of the soil, consisted predominantly, if not entirely, of the Montmorillonite group of minerals. Tyagi (1973) reports presence of Nontronite-Beidellite type mineral from a sample of black cotton soil based on X-ray and D.T.A. Identification of the minerals of Montmorillonite group in black cotton soil is consistent with their high cation exchange capacity (C.E.C.) which ranges from 50-70 meq/100 gm for - 36 and -44 sieve fractions to 70-144 meq/100 gm for fractions less than 2 microns (Banerjee 1970; Katti 1966). These authors have also attributed the poor horizonation of black cotton soils due to the mixing up, both horizontally and vertically, of the soil material consequent to alternate

swelling and shrinkage. In the following table is contained the average chemical composition of black cotton soils from Malwa Plateau and Maharashtra -

Table No.2

	(1)*	(2)**	(3)***
SiO <sub>2</sub>	57.50	63.20	53.40
Al <sub>2</sub> O <sub>3</sub>	19.60	17.50	27.70
Fe <sub>2</sub> O <sub>3</sub>	12.10	9.20	9.15
CaO	5.20	3.88	1.04
MgO	3.80	3.20	5.18
K <sub>2</sub> O	N.D.	2.41	2.79
TiO <sub>2</sub>	1.62	1.11	1.05
MnO	N.D	0.21	0.75
SiO <sub>2</sub> /Al <sub>2</sub> O <sub>3</sub>	2.92	3.61	1.93
SiO <sub>2</sub> /R <sub>2</sub> O <sub>3</sub>	1.81	2.38	1.44

(1) \* Katti(1966), average of 14 analyses from different localities in Maharashtra. Averaged and recalculated to 100 on ignited basis.

(2) \*\* Banerjee (1970), average of 5 samples from Indore as % on ignited basis.

(3) \*\*\* ———(1970) , average of 5 samples (clay fraction only) as % on ignited basis.

### 2.3.2 Laterite Materials:

A general term "laterite materials" has been used (Gidigas, 1974) to cover a variety of reddish, tropically weathered decomposition products, residual or non residual,



differing widely in regard to their chemical, mineralogical, textural and for that matter , their geotechnical characteristics. Such a term, obviously, does not have any chemical textural or morphological implications or reference to the hardening properties of laterite (sensu stricto ) and includes both the "laterite" and "lateritic soils". On the other hand, Alexander and Cady, (1962; as quoted by Lohnes and Demirel, 1973) have defined "laterite" as "... a highly weathered material rich in secondary oxides of iron, aluminium or both. It is nearly devoid of bases and primary silicates but it may contain large amounts of quartz and Kaolinite. It is either hard or capable of hardening on exposure to wetting and drying". Soils possessing all the characters listed in the above definition except the property of hardening can be called "lateritic soils". However, to avoid confusion, it may be mentioned here that the presence or otherwise of quartz in such a soil would depend upon the parent rock. Similarly, Kaolinite may give place to Montmorillonite depending upon the climate and drainage conditions.

Lohnes and Demirel (1973) studied engineering behaviours of lateritic soils of Puerto Rico representing various states of weathering and found that engineering properties showed systematic trend in relation to the "degree of weathering". For a given rock, the void ratio is decreased and cohesion and specific gravity increased as weathering proceeds. This is due to increasing crystallization and cementation by

sesquioxides. They also found that the specific gravity increases with increasing degree of weathering and it can be a promising index property to characterise these soils, in so far as it reflects iron oxide content. All the Puerto Rican soils showed low activity ( 0.1 to 0.56) and are rated as inactive according to Skempton (1953). Kaolinite content decreased as mean annual rainfall increased; in the light of severity of weathering the least weathered soils contained the smallest Kaolinite and the most weathered ones had the highest Kaolinite content (Lohnes and Demirel , 1973).

Literature concerning engineering behaviour of "laterite materials" has been critically reviewed by Gidigas (1974), who realised that geotechnical characteristics depend mainly on genesis and "degree of weathering" (i.e. decomposition, laterization, dessication and/or hardening ). Besides these , the other significant controles are morphological characteristics as well as type and content of secondary minerals. Specific gravity , saturation moisture content, sensitivity to drying and remoulding, potential swell and self stabilization have been identified as significant geotechnical parameters useful in identification and evaluation of laterite materials for engineering purposes.

### CHAPTER-III

#### FIELD WORK AND ANALYTICAL PROCEDURE

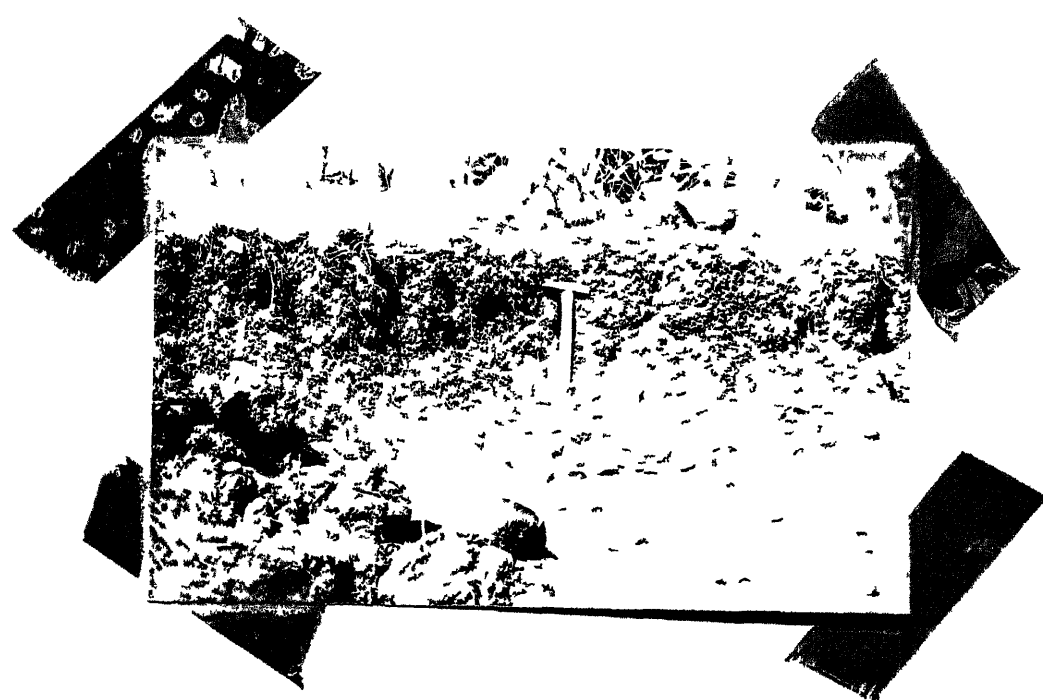
##### 3.1 Field Work.

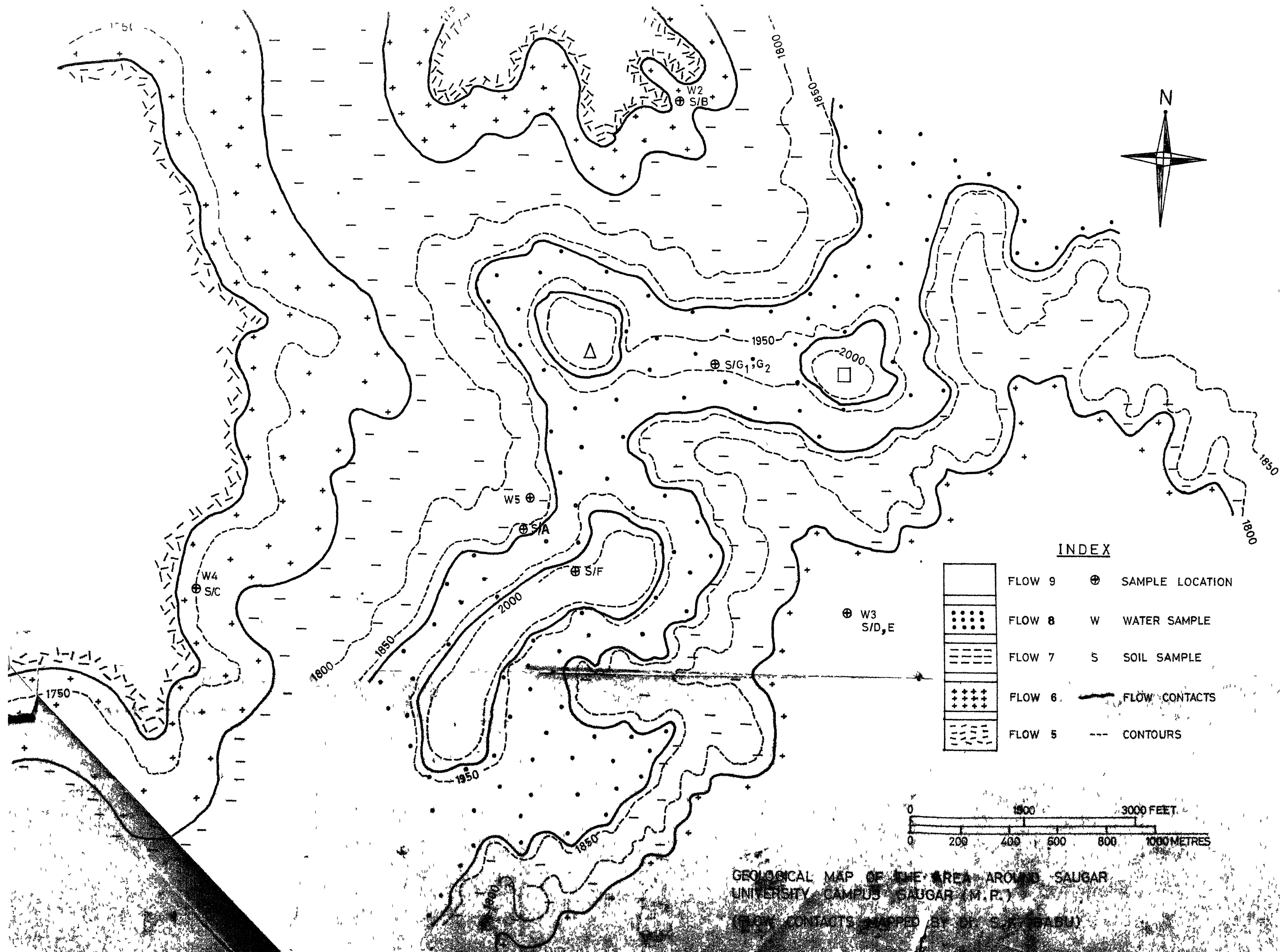
Field work was carried out to collect water, soil, and rock samples from three selected areas in the Eastern, South Eastern and Western Malwa Plateau, viz., around Sagar, Titarpani ( 51 miles South East of Sagar), and Mehidpur (24 miles North of Ujjain), respectively. Out of the eleven water samples eight ( No. 1 to 4 and 6 to 9) are from open wells in Trap, one (No.5) from seepage through flow 7 around Sagar; and two (No.10 and 11) from springs, one in Trap itself and the other at the contact between the Trap and infratrappean Lametas (calcareous orthoquartzitic sand stones). Depth of water in the wells from the surface as well as depth of wells was measured wherever possible. Temperature and pH of the water samples was measured in the field. Water samples were collected in double stoppered polythene bottles taking care not to entrap air bubbles.

Four months after the collection of first-set of water-samples in October 1974, a second trip to the field was undertaken in March 1975 to duplicate some of the water samples (No. 1 , 2 , 3 , 4 , 6 and 9 ). The main purpose of this trip was to check the change in the bulk chemical composition of the waters, if any.

From 9 different locations 13 soil samples were collected and stored in double polythene bags to preserve the field moisture content. Samples were obtained from hill-tops as well as foot-hill regions. Those from the foot-hills were collected, as far as possible, from near the wells from which water samples were obtained. At most of the places, soil profiles directly overlie the 'saprolite' (murram) zone. Wherever good sections were exposed samples were obtained depth-wise (although profiles more than 0.75 m were not seen) and numbered with a subscript such as A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub> or G<sub>1</sub> and G<sub>2</sub>. It has been observed that in a Trap country soils on hill-tops (such as on 9th and 8th flow around Sagar) are invariably red or reddish-brown ("lateritic"), where as those on the intermittent plains of the foot-hill region are usually black. Out of 13 samples, four ( No. F , G<sub>1</sub> , G<sub>2</sub> , and E<sub>1</sub>) have been termed "lateritic soils" on visual basis. Sample E<sub>2</sub> has been taken to be representative of "C<sub>1</sub>" horizon, geomorphologically. It consists predominantly of the unweathered and partly weathered primary minerals and very little clay fraction.

Rock samples (fresh as well as partly weathered) had been collected from several locations. Geology and location of the water and soil samples from around Sagar is shown in figure number . The following table shows location of soil and water samples:-





# INDEX

[Symbol: Horizontal lines]	FLOW 9	⊕	SAMPLE LOCATION
[Symbol: Dotted pattern]	FLOW 8	W	WATER SAMPLE
[Symbol: Dashed pattern]	FLOW 7	S	SOIL SAMPLE
[Symbol: Cross-hatched pattern]	FLOW 6	—	FLOW CONTACTS
[Symbol: Wavy pattern]	FLOW 5	- - -	CONTOURS

GEOLOGICAL MAP OF THE AREA AROUND SAUGAR  
 UNIVERSITY CAMPUS SAUGAR (M.P.)  
 (FLOW CONTACTS SHOWN BY DR. S. P. PABU)

Table No.3  
Location of Water and Soil Samples

Location	Water Sample No.	Nearest Soil Sample No.
Around Sagar University Campus, Sagar, M.P.	1	-
	2	B
	3	D & E
	4	C
	5	A
Around Mehidpur, District Ujjain, (M.P.)	6	-
	7	-
	8	-
	9	Me
Around Titarpani, District Sagar, (M.P.)	10	Mr
	11	-

### 3.2 Apparatus Used

The following apparatus were used for experimental work.-

1. Microscope (Meopta-Czechoslovakia) fitted with electrical point counter.
2. PHILIPS pH meter (Philips, India).
3. Bausch and Lomb Spectronic 20 Colorimeter/  
Spectrophotometer(Bausch and Lomb Co., Rochester, N.Y., 14602 U.S.A.) .

4. Conductivity cell (Philips, India) and conductivity bridge.
5. Systronics-121 MK-I flame photometer (Systronics, Ahmedabad, India).
6. XRD-5 30 KV X-ray Diffractometer (General Electric, U.S.A.).
7. Du Pont-900 Differential Thermal Analyser ( Du Pont,USA)

### 3.3 Analytical Methods

#### 3.3.1 Water

Chemical analyses of water have been carried out by methods described in Standard Methods ( 12th Edition).

- a). Total dissolved solids (T.D.S.) have been evaluated by measuring specific conductance using a conductivity bridge and a conductivity cell.
- b). Calcium and Magnesium have been evaluated by E.D.T.A. titrations using Ammonium Purpurate and Eriochrome Black T as indicators for calcium and total hardness respectively.
- c). Sodium and Potassium have been evaluated by flame photometric method using respective filters.
- d). Total Iron has been evaluated as  $\text{Fe}^{++}$  by Colorimetric method using hydroxylamine and phenanthroline reagents.
- e). Silica was determined by Colorimetric molybdo-silicate method using Ammonium Molybdate reagent.
- f). Carbonate and bicarbonate ion concentrations have been evaluated by determining the phenolphthalein and Methyl Orange alkalinity using  $\text{H}_2\text{SO}_4$  titrant.
- g). Chloride has been evaluated by  $\text{AgNO}_3$  titration using potassium chromate indicator.



h). Sulphate ( $\text{SO}_4^{2-}$ ) has been evaluated by turbidimetric method using Barium Chloride reagent.

### 3.3.2 Trap Soils

a) Soil pH was measured by ISI method using 1.3.3 soil water suspension.

b) Engineering Index Properties, viz., specific gravity, atterberg limits and grain size analysis, were evaluated using ASTM procedures.

c) For mineralogical work, the clay fraction was separated from the fraction passing 36 (BSS) sieve by decanting from a water suspension. Oriented slides were prepared and X-ray diffractometer studies on 4 types of material was done using Fe k radiation.

1) Treated with dilute HCl for 24 hours at room temperature

1i) Untreated

1ii) Glycolated (untreated samples were taken for this)

1v) Glycolated ones after the run are heated to 550 °C and run again.

Differential thermal analysis was done on two types of materials:

1) Untreated and unseparated samples finely powdered.

1i) Clay fraction treated first with HCl to decompose carbonate and then with  $\text{H}_2\text{O}_2$  ( 20 % solution ) to decompose organic matter.

3.3.3 Trap Rock;

a) Volume percentate of minerals in the basalt rock has been evaluated from the thin sections using an electrical point counter fitted on the microscope stage.

b) The composition of plagioclase felspar and the clino-pyroxene has been evaluated petrographically as well as by X-ray diffraction.

## CHAPTER-IV

### RESULTS AND DISCUSSIONS

#### 4.1 Country Rock

Samples of basalt were collected from around Sagar, Mehlapur and Titarpani as described in Chapter III. Thin section studies revealed that these are typical Deccan basalts constituted in bulk by pyroxene, plagioclase feldspar and glass. Magnetite, palagonite (altered glass), iddingsite (pseudomorph after olivine) and a micaceous mineral occur as accessories. X-ray diffraction patterns indicate that the plagioclase is between bytownite and anorthite in composition and the pyroxene is of the augite type (Table 4). Modal analysis (Table 5) of the 5th flow aquifer around Sagar shows 49.5 % pyroxene, 21.6% plagioclase, 20.5 %, glass, 5.6 % palagonite, 2.1 % magnetite, 0.8 % iddingsite, 0.1 % mica by volume.

In some thin sections pyroxene was observed to alter to epidote and mica. Differences were also observed in the size and relative abundance of phenocrysts, size and shape of magnetite crystals and colour of palagonite in samples from various basalt flows.

#### 4.2 Weathered Rock and Soil

Thin section of the partly weathered rock around Titarpani showed alteration of pyroxene to epidote and

Table No. 4

## Results of X-Ray Diffraction on Fresh and Weathered Basalt

Anorthite <sup>1</sup>	Bytownite <sup>2</sup>	5th Flow <sup>3</sup>	W.R. <sup>4</sup>	Augite <sup>5</sup>	5th Flow <sup>3</sup>	W.R. <sup>4</sup>							
d(Å)	I/I <sub>0</sub>	d(Å)	I/I <sub>0</sub>	d(Å)	I/I <sub>0</sub>	d(Å)	I/I <sub>0</sub>						
		Observed Values		Observed Values		Observed Values							
6.42	1	6.52	40	3.76	41	6.45	9	2.99	100	3.01	100	3.00	100
3.76	13	3.75	80	3.64	19	3.75	19	2.94	75	2.94	75	2.94	75
3.62	25	3.62	70	3.34	60	3.65	45	2.86	60	2.12	75	2.13	75
3.37	25	3.36	60	3.21	75	3.219	100	2.56	85	1.816	50	2.02	75
3.21	35	3.20	100	3.18	100	3.183	75	2.51	85	1.77	75	1.98	50
3.20	100	3.17	80	2.48	22	2.90	12	2.13	75	1.49	50	1.81	75
3.18	75	3.12	60			2.620	10	2.04	75			1.62	100
3.12	45	2.94	70			2.520	29	2.00	60			1.53	60
2.935	17	2.92	50			2.500	25	1.97	50			1.458	25
2.895	7	2.65	60					1.82	75			1.41	85
2.65	11	2.52	70					1.78	25			1.37	50
2.525	25							1.74	75			1.34	85
2.502	25							1.62	100			1.29	90
2.50	25							1.53	60				
								1.49	50				
								1.46	25				
								1.41	85				
								1.38	50				
								1.28	86				

Table No. 5

## Modal Composition of 5th Flow Basalt Around Sagar

Thin Section No.	Points Counted	Pyroxene (Augite) Vol. %	Plag. Felspar Vol %	Glass Vol %	Palagonite Vol %	Magnetite Vol %	Iron-oxide Vol %	Micaceous Minerals Vol %
1	3204	46.40	20.20	24.30	6.65	2.00	0.20	0.00
2	2796	52.60	23.10	16.20	4.65	2.30	1.40	0.21
Average		49.50	21.65	20.50	5.60	2.15	0.80	0.10
Specific Gravity		3.30	2.71	2.90	2.80	5.00	3.30	2.65
Wt. %		52.70	18.90	19.20	5.10	3.45	0.85	0.10

sericitisation of feldspar. Replacement of feldspar by palgonite and the carbonate minerals (probably calcite) was also observed.

The soils of this area were classified as red and brown (lateritic) and black soil on the basis of field observations (Chapter III). The D.T.A. patterns of the untreated black soils (Me and Mr in Fig.3) show presence of quartz and montmorillonitic clay mineral. Separation of the clay fraction treatment with HCl and H<sub>2</sub>O<sub>2</sub> synthesizes typical endothermic montmorillonite peaks around 100-200, °C 500-600 °C, 750-850 °C and exothermic peak between 900-950 °C. There is no obvious difference in the DTA patterns for black and red soils (Figs. 3 to 5). Although differences in certain physical properties were observed as discussed below. X-ray diffraction of the untreated bulk soil samples showed ubiquitous occurrence of calcite and quartz. The clay fraction of most of the black soil samples showed the characteristic 15 Å peak for montmorillonite in FeK $\alpha$  radiation which swells to 17 Å on glycol saturation and collapses to 9.8 Å after heat treatment (Fig. 6). Sample number 'C' from foot hill region around Sagar showed the presence of kaolinite and illite in addition to montmorillonite in its X-ray pattern. The DTA pattern of the same sample also shows the peaks characteristic of illite-kaolinite - montmorillonite mixture (Grim 1968; p.348-349).

X-ray diffraction pattern of the red soils do not show any clay peaks. On the other hand presence of ferric oxide is indicated. As mentioned earlier, the DTA patterns of the same soils suggest a montmorillonite minerals. It is possible that X-ray peaks are suppressed by iron interference or else the mineral is X-ray amorphous.

The grain size analysis of the soil samples is given in the Table No. 6 and Figure No.7

Table No. 6

Grain Size Analysis of Deccan Trap Soils

Sample No.	Sand %	Silt %	Clay 2 %	$\frac{\text{M. Sec.}}{\text{M. Pr.}} \times 100$
A <sub>2</sub>	15.0	42.0	43.0	75.3
B	30.0	57.0	13.0	15.0
E <sub>1</sub>	54.0	43.0	3.0	3.1
G <sub>2</sub>	11.5	42.5	46.0	85.0
F <sup>2</sup>	30.5	61.5	8.0	8.7
G <sub>1</sub>	33.0	54.0	13.0	15.0

Soil F from the top most elevation around Sagar ( 9th flow) has low clay content and low degree of decomposition. The latter property is expressed in terms of a ratio equal to total secondary mineral (clay fraction 2 ) is to total primary material ( silt + sand ) after Wehnert (1964) quoted by Gidigas ( 1974). According to this author the ratio 15 % indicates fresh rock, 15-30 % decomposed, 30 % badly decomposed material and 100 % as residual soil.

Soils on the foot hill  $A_2$  & B in general have higher clay content and degree of decomposition. It is interesting to note that the upper profile of soil 'G' on the hill slopes ( $G_1$ ) has a lower degree of decomposition compared to the lower profile ( $G_2$ ). The physical properties of ' $G_2$ ' are in fact similar to the soil on the foot hills. Profile ' $E_1$ ' although occurring on the foot hill (flow 5th), appears to be poorly developed in terms of clay content and the degree of decomposition.

Determination of the Atterberg limits and an A-line plot classifies the soils in two distinct groups (Table No. 7, fig. No. 8).

Soil  $A_2$ ,  $A_3$ , B, C, and D are all black soils occurring in the foot-hill and have a higher liquid limit and plasticity index and low shrinkage limit. It can be classified as CH-MH. On the other hand, soil ' $F$ ', ' $G_1$ ' and ' $G_2$ ' are classed as CL-ML. The immature soil ' $E_1$ ' and ' $E_2$ ' although occurring in the foot-hills are grouped in the second class. The second group was also classified as "lateritic" soil on the basis of field criteria. It will thus appear that the montmorillonitic soils in the poorly drained foot hills are darker in color, low in specific gravity, higher in clay content, more plastic, and have reportedly high C.E.C (average 50 meq/100 gms as mentioned by Simonson, 1954). The development of ferric oxide minerals in the better drained hill top and hill-slopes reduces the clay content, plasticity index and increases the shrinkage limit. It is also <sup>apparent</sup> that differences in conventional Atterberg limits of soils developed on a given rock type under a given climatic conditions is controlled by the soil mineralogy which in turn depends on the drainage condition and oxidising environment.



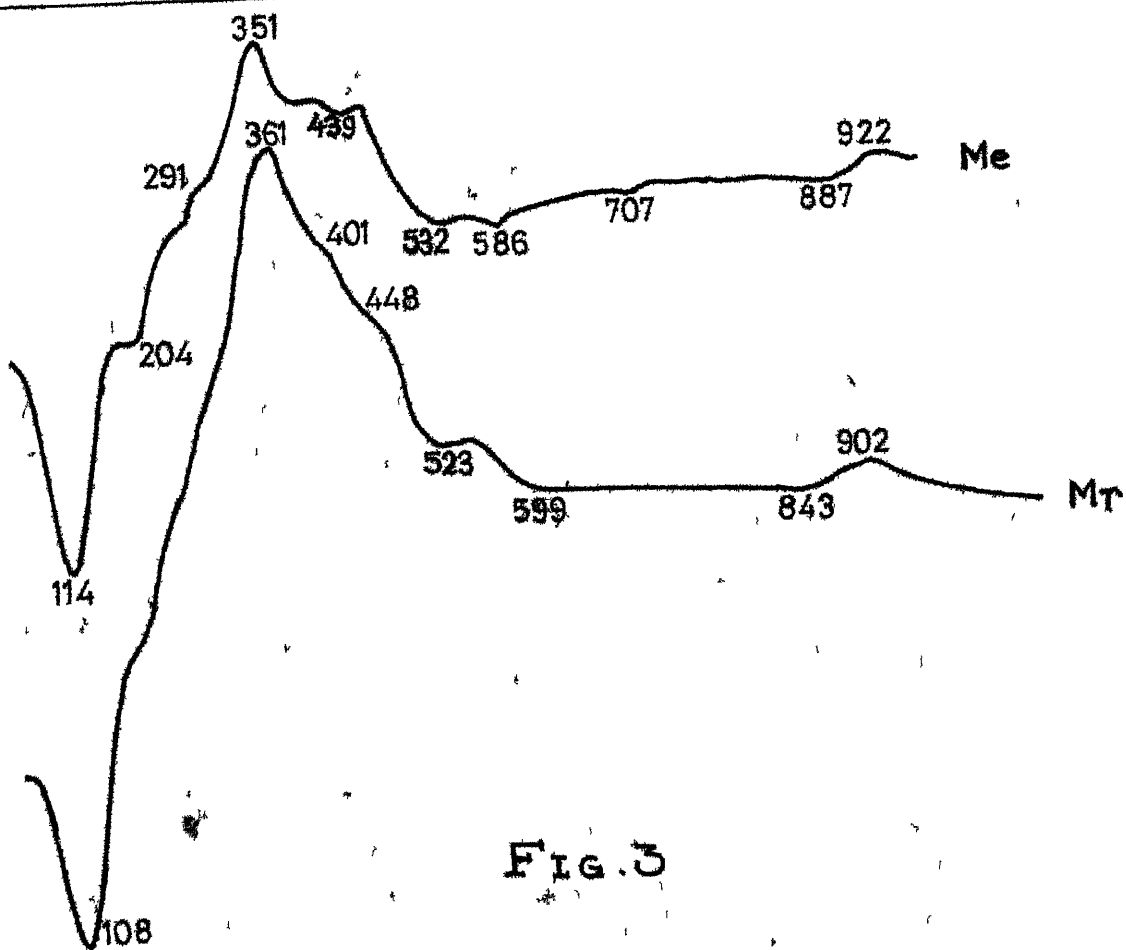
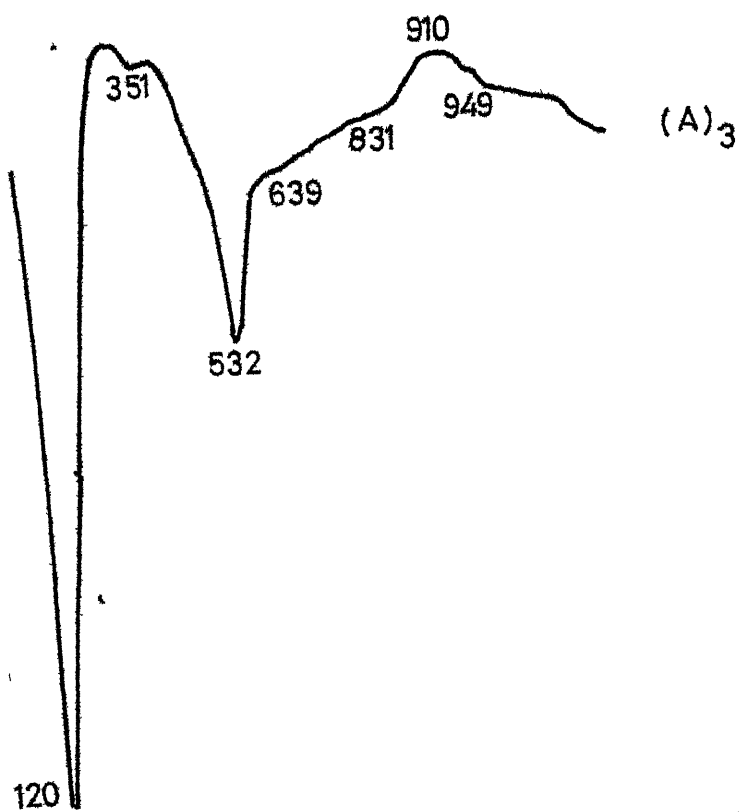


FIG. 3

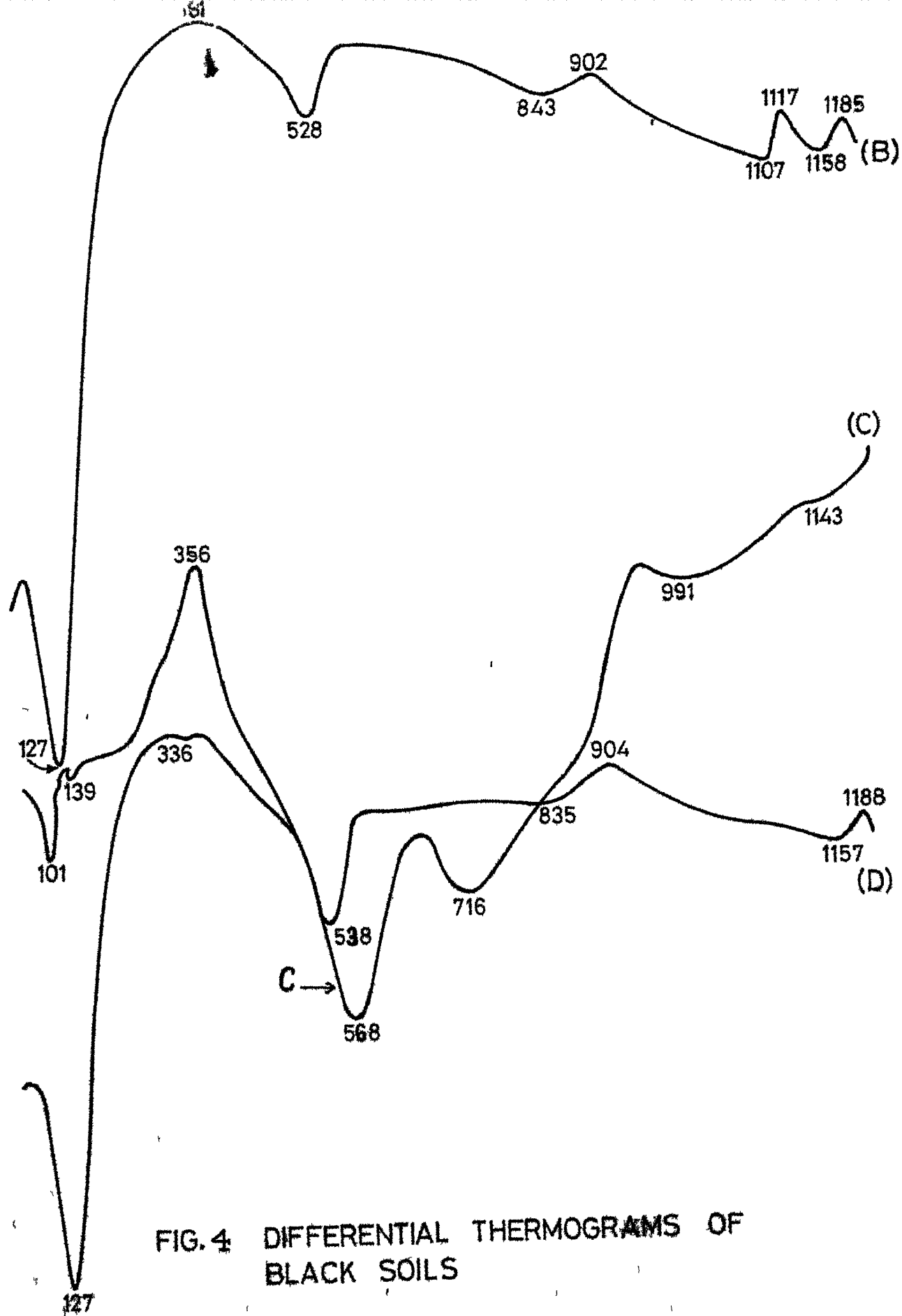


FIG. 4 DIFFERENTIAL THERMOGRAMS OF BLACK SOILS

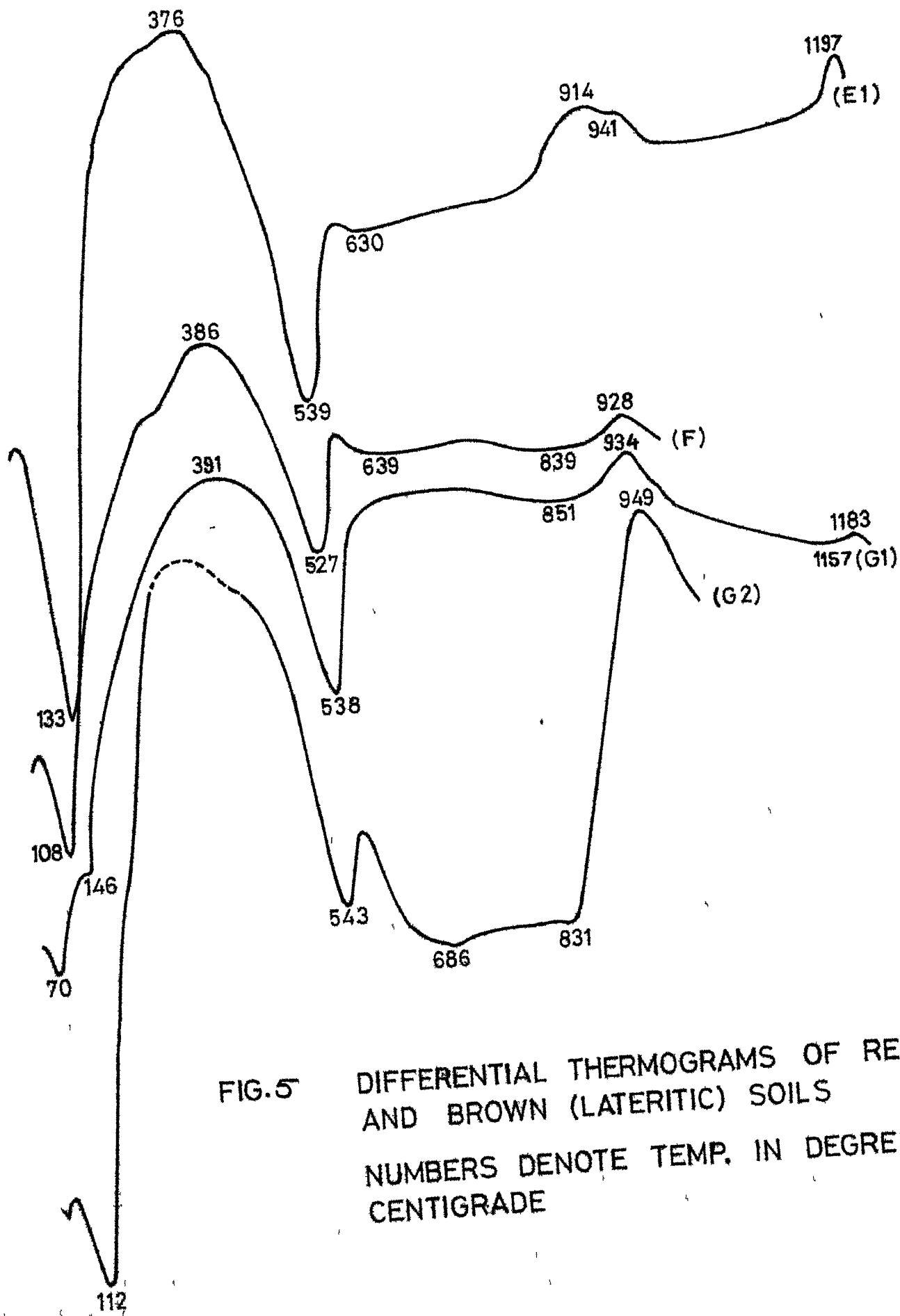
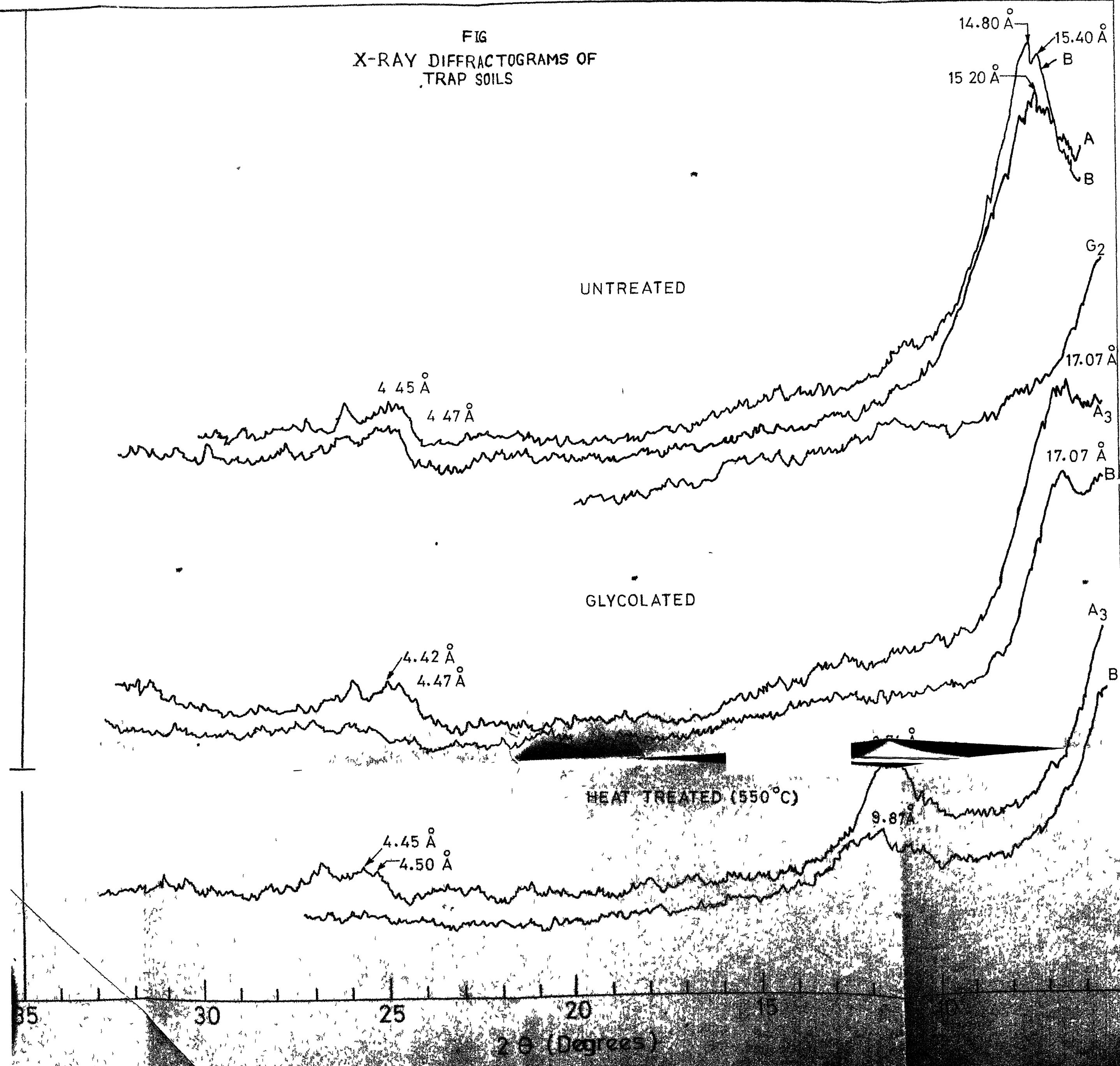


FIG. 5 DIFFERENTIAL THERMOGRAMS OF RED AND BROWN (LATERITIC) SOILS  
NUMBERS DENOTE TEMP. IN DEGREES CENTIGRADE

FIG  
X-RAY DIFFRACTOGRAMS OF  
TRAP SOILS



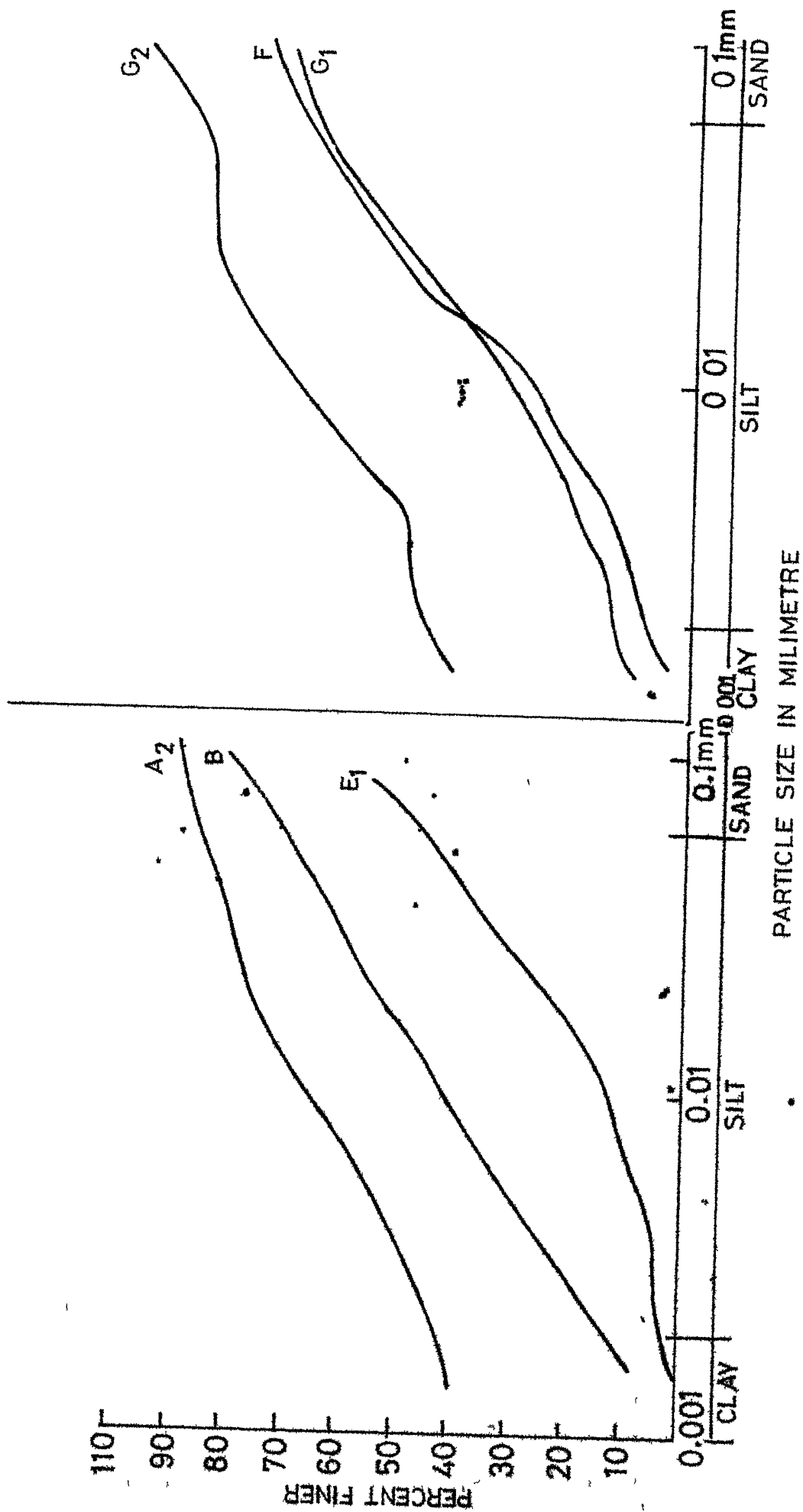


FIG 7 GRAIN SIZE ANALYSIS OF TRAP SOILS

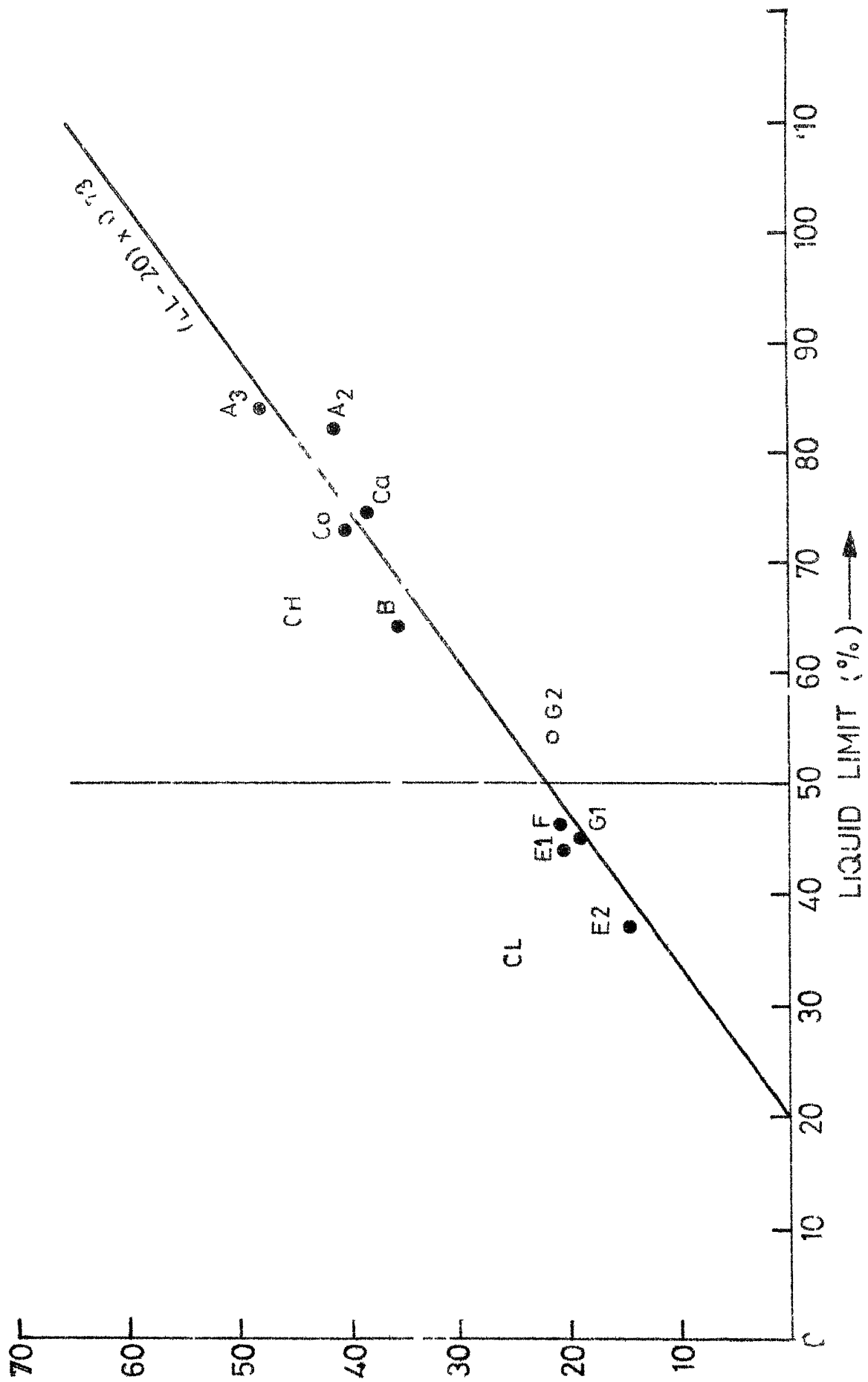


FIG. 8

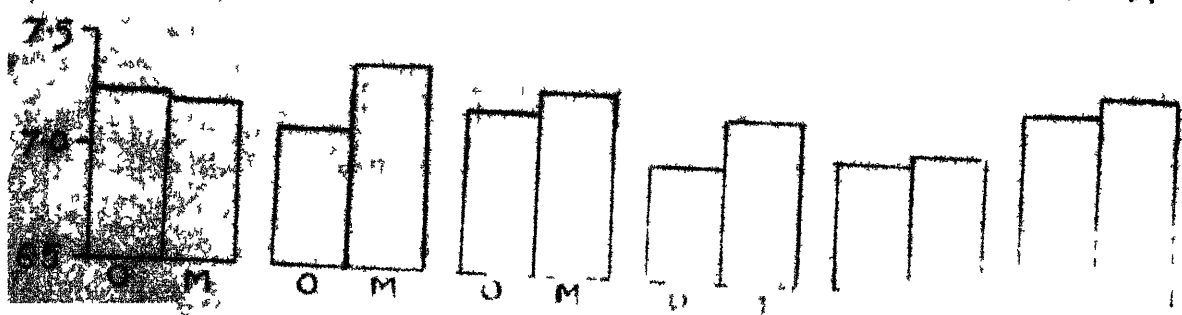
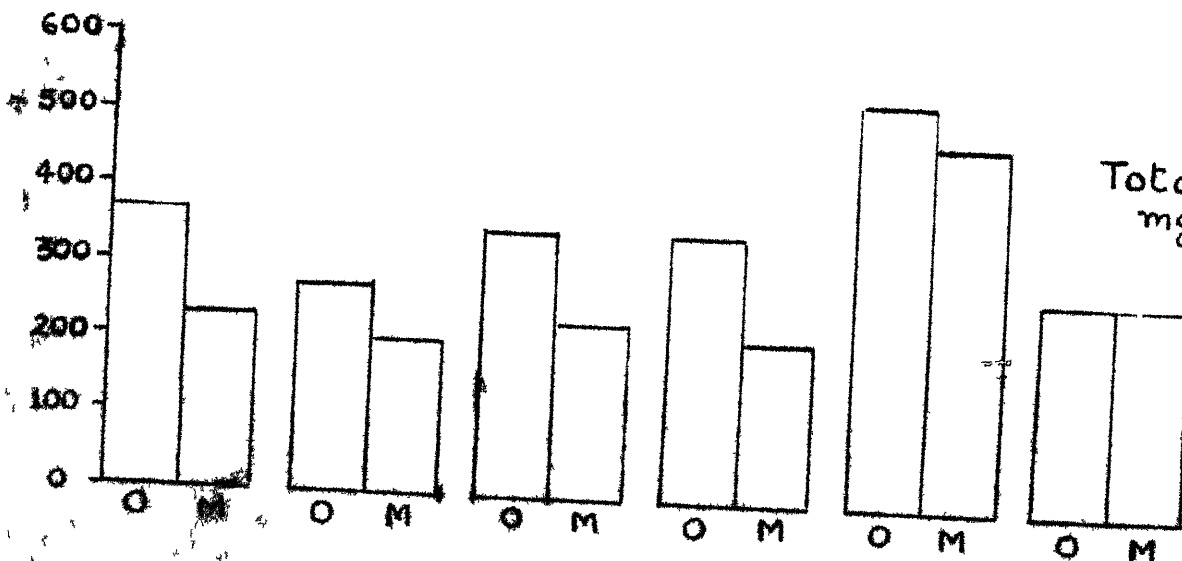
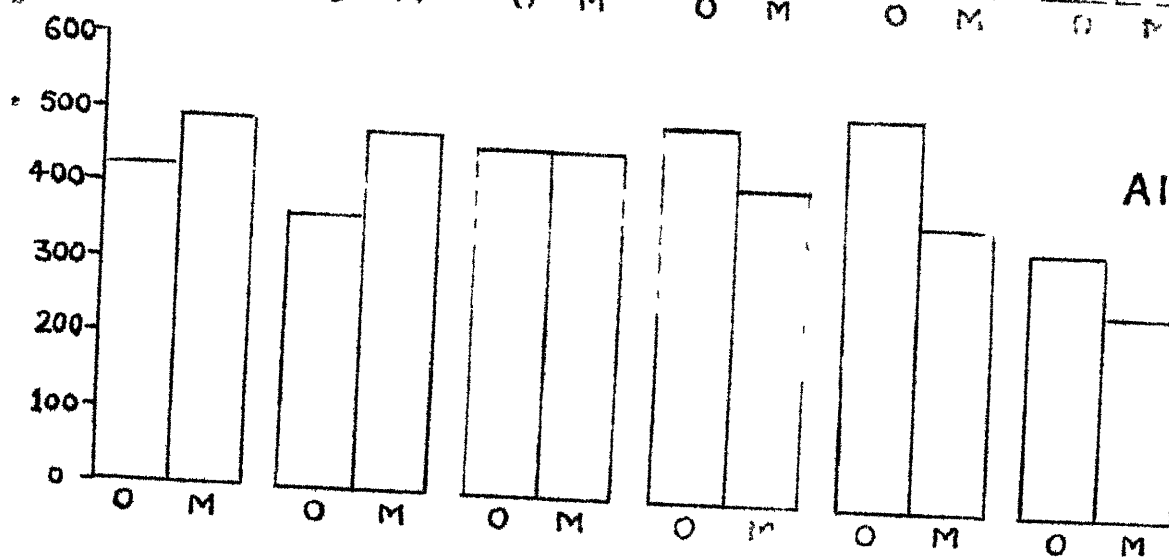
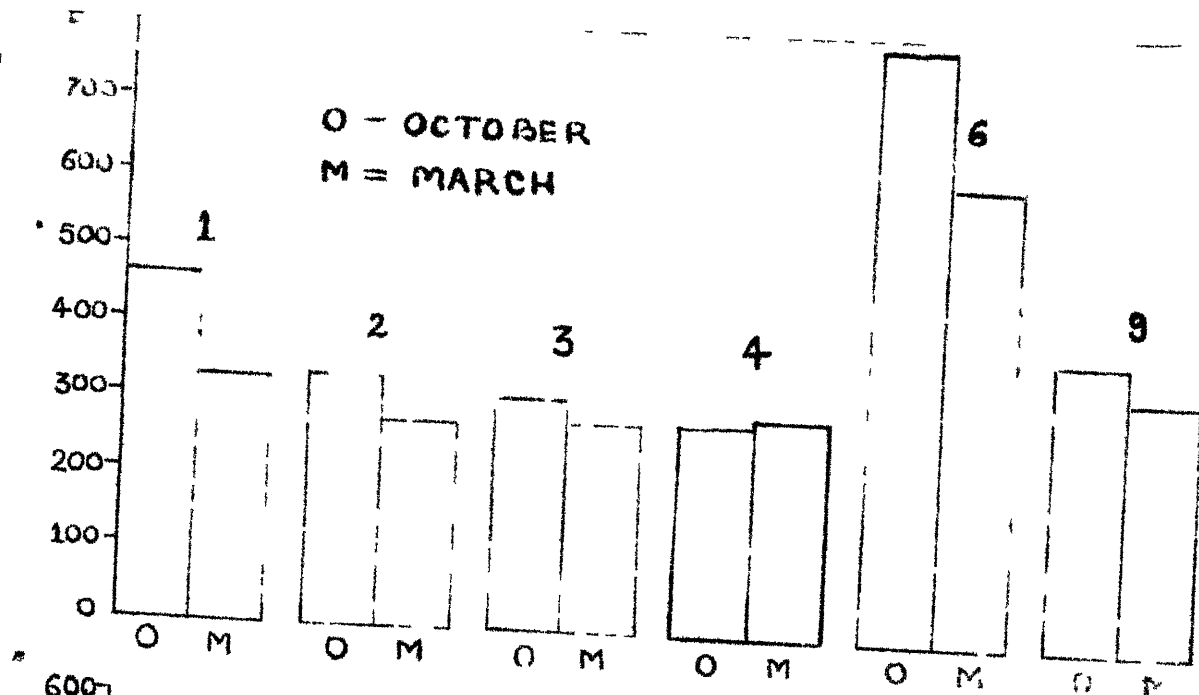
TABLE NO. 7

Results of tests for engineering index properties on Trap Soils

	Sample No.	Soil Horizon	Sample Depth cms.	Colour	Treatment -36 B S.S.	Plastic Limit %	Liquid Limit %	Shrinkage Limit %	P.I. (LL-PL)	Sp. Gr.	Volumetric Shrinkage %	Unified Soil Class	Clay Min. X-Ray
M A T U R E S O I L S	A <sub>3</sub>	A	40- 60	Black	Oven Dried	36. 0	84. 0	14. 6	48	2. 62	72. 8	CH-MH	Mont.
	A <sub>2</sub>	A	22- 40	Black	Air Dried	40. 8	82. 0	14. 8	41. 2	-	61. 8	MH	-do-
	B	A	0- 15	Black	Air Dried	28. 3	64. 0	15. 3	35. 7	2. 64	57. 6	CH	-do-
	C <sub>0</sub>	A	0- 10	Black	Oven Dried	33. 1	73. 1	13. 5	40. 0	2. 60	67. 6	CH-MH	Mont+Il. +Kaol.
	C <sub>A</sub>	A	0- 10	Black	Air Dried	36. 3	74. 4	8. 25	38. 1	-	69. 6	MH	-do-
	D	A	0- 30	Black	-	-	-	-	-	2. 74	-	-	Mont.
	M <sub>e</sub>	A	-	Black	-	-	-	-	-	2. 61	-	-	Mont.
	M <sub>r</sub>	A	-	Black	-	-	-	-	-	2. 57	-	-	Mont.
I M M A T U R E S O I L S	E <sub>1</sub>	A	0- 15	Brown	Air Dried	23. 5	44. 0	15. 7	20. 5	2. 78	31. 5	CL	Fe- Oxide
	E <sub>2</sub>	C	15-24	Reddish Brown	Air Dried	22. 5	37. 0	25. 1	14. 5	2. 89	16. 3	-	- do -
	F	A	0- 40	Reddish Brown	Air Dried	25. 4	46. 0	19. 2	20. 6	2. 85	29. 8	CL	- do -
	G <sub>1</sub>	A	0- 18	Reddish Brown	Air Dried	26. 2	45. 0	19. 9	18. 8	2. 95	30. 1	CL-ML	- do -
	G <sub>2</sub>	B	18- 54	Reddish Brown	Air Dried	32. 7	54. 0	27. 8	21. 3	2. 76	38. 3	MH	- do -

O - OCTOBER  
M = MARCH

FIG. 9





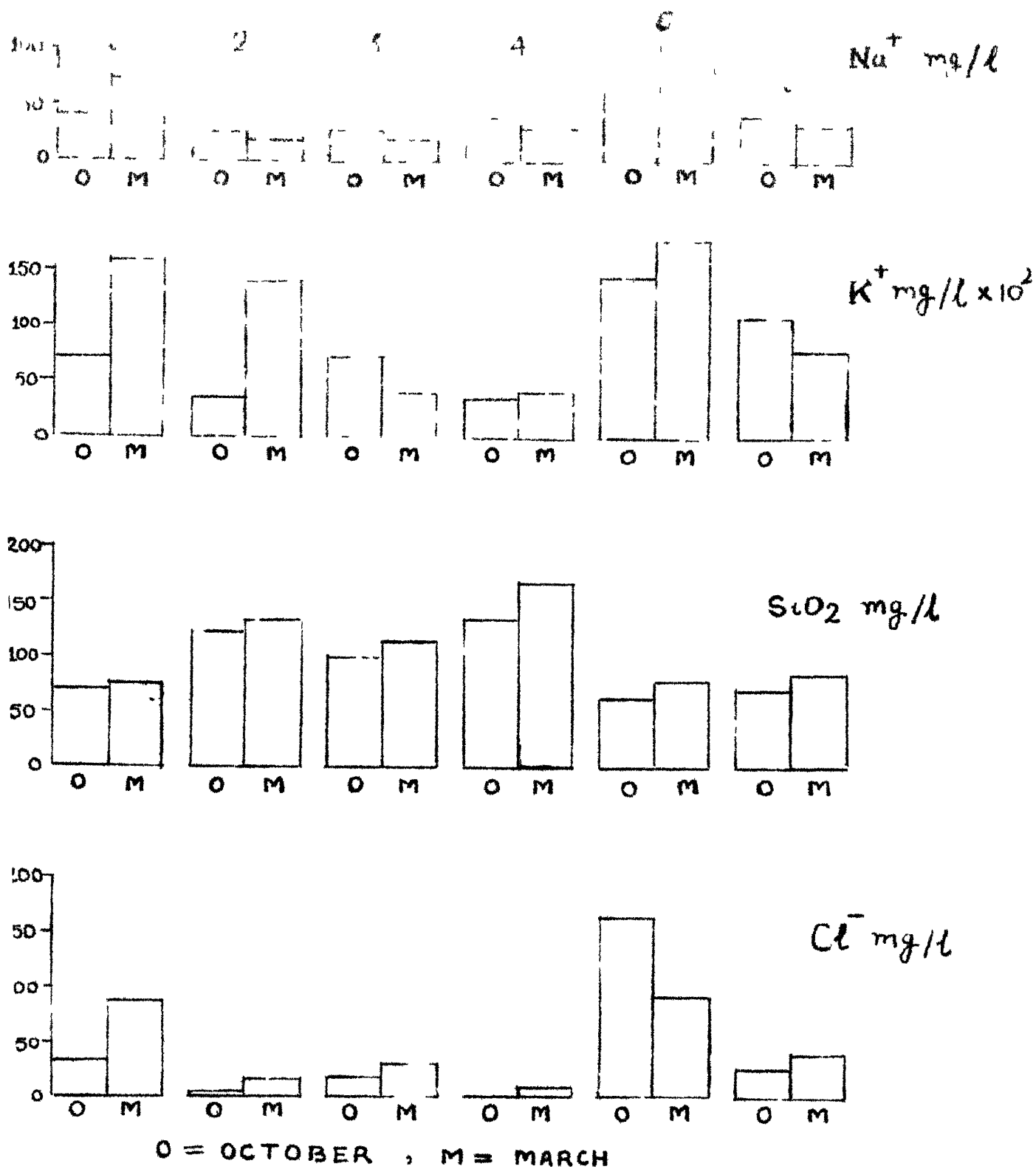


FIG. 10

another physical property which has been used commonly to describe the black soils on basaltic rocks is black color. In course of this study it was observed that the black color disappears on heating at about 350°C or HCl and H<sub>2</sub>O<sub>2</sub> treatment followed by oven drying. It is concluded that the color of the black soils is due to the organic matter (clay - humic complex).

#### 4.3 Ground water Quality

Results of the chemical analyses of waters are given in the table No. 8. and 9. All the waters are near natural, total dissolved solids range from 325 to 700 mg/l, bicarbonate alkalinity ranges from 300 - 500 mg/l as CaCO<sub>3</sub>. Important cations are Ca<sup>++</sup>, Mg<sup>++</sup>, Na<sup>+</sup> and K<sup>+</sup>. These are balanced by the anions, HCO<sub>3</sub><sup>-</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>=</sup>. The ionic strength was calculated as :-

$$I = 1/2 \sum m_i z_i^2$$

Where m<sub>i</sub> = concentration in moles/l of the ion

z<sub>i</sub> = charge on the ion

The average value of I for these waters is 0.012. Knowing the 'I' and the molar concentration the thermodynamic activity of the chemical constituent was calculated according to the standard physical chemistry method (Krauskopf 1967). These then help in comparing the water analyses to their environment & stability of soil minerals found in the field. As mentioned in chapter III the second field trip was undertaken in March 1975 to duplicate some of the water samples and demonstrate the seasonal variation in composition (Table No. 10, fig. No. 9 and 10). Compared to the post monsoon values in October the premonsoon values in March shows a higher concentration of Na<sup>+</sup>, K<sup>+</sup>, SiO<sub>2</sub>, Cl<sup>-</sup>, and slightly higher pH value. On the other hand, TDS, alkalinity and total hardness show a general downward

Table No. 8  
Results of Chemical Analyses of Ground Water Samples  
(All Values in Mg/l. )

Sample No.	1	2	3	4	6	8	9	10	11
Temp. °C	27.0	27.0	27.5	27.0	26.0	27.0	27.0	26.3	26.50
pH	7.25	7.1	7.2	7.0	7.05	7.15	7.3	7.2	7.45
T.D.S.	459.0	332.0	306.0	281.0	791.0	383.0	383.0	540.0	410.00
Phenol.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alk.									
Bicarb.	426.0	364.0	463.0	504.0	520.0	307.0	348.0	364.0	396.0
Alk.									
Total Hardness as CaCO <sub>3</sub>	368.0	268.0	346.0	350.0	534.0	313.0	279.0	284.0	302.0
Ca-Hardness as CaCO <sub>3</sub>	130.0	185.0	55.0	37.0	157.0	103.0	93.0	215.0	168.0
Mg-Hardness	71.0	123.0	100.00	134.0	63.0	58.0	69.0	79.0	93.0
Ca++	238.0	83.0	291.00	313.0	377.0	210.0	186.0	69.0	134.0
Mg++	52.0	74.0	22.0	15.0	63.0	41.0	37.0	86.0	67.2
Total Iron As Fe++	57.8	19.7	70.7	73.0	89.6	49.8	44.3	16.4	31.9
Na+	39.0	24.5	27.0	38.0	86.0	54.0	41.0	19.0	24.0
K+	725	364	725	364	1.46	0.91	1.09	455	0.91
HCO <sub>3</sub> <sup>-</sup>	520	444.0	565.0	614.0	633.0	374.0	425.0	444.0	482.0
Cl <sup>-</sup>	33.0	5.0	17.0	0.0	161.0	61.0	24.0	13.5	6.1
SO <sub>4</sub> <sup>=</sup>	20.0	5.0	8.0	6.5	71.0	44.0	15.0	1.5	1.5

Table No. 9

66

Results of Analyses of Ground Water (All values in moles/litre)

Sample No.	H <sup>+</sup>	SiO <sub>2</sub> (x10 <sup>-3</sup> )	Mg <sup>++</sup> (x10 <sup>-3</sup> )	Ca <sup>++</sup> (x10 <sup>-3</sup> )	Fe <sup>++</sup> (x10 <sup>-3</sup> )	Na <sup>+</sup> (x10 <sup>-3</sup> )	K <sup>+</sup> (x10 <sup>-3</sup> )	HCO <sub>3</sub> <sup>-</sup> (x10 <sup>-3</sup> )	Cl <sup>-</sup> (x10 <sup>-3</sup> )	SO <sub>4</sub> <sup>=</sup> (x10 <sup>-3</sup> )
1	10 <sup>-7.25</sup>	1.13	2.38	1.30	0.0089	1.695	0.0186	8.52	0.93	0.208
2	10 <sup>-7.1</sup>	2.02	0.83	1.85	0.0179	1.065	0.0093	7.32	0.141	0.052
3	10 <sup>-7.2</sup>	1.64	2.91	0.55	0.0044	1.175	0.0186	9.30	0.480	0.083
4	10 <sup>-7.0</sup>	2.20	3.13	0.37	0.0089	1.650	0.0093	10.10	N.I.	0.068
5										
6	10 <sup>-7.05</sup>	1.03	3.77	1.57	0.0044	3.740	0.0374	10.40	4.54	0.740
7										
8	10 <sup>-7.15</sup>	0.95	2.10	1.03	0.0089	2.350	0.0233	6.13	1.72	0.458
9	10 <sup>-7.3</sup>	1.13	1.86	0.93	0.1000	1.780	0.0288	6.97	0.675	0.156
10	10 <sup>-7.2</sup>	1.295	0.69	2.15	0.0043	0.825	0.0117	7.30	0.380	0.015
11	10 <sup>-7.45</sup>	1.52	1.34	1.68	0.0033	1.040	0.0223	7.93	0.172	0.0156

Table No. 10

## Seasonal Change of Water Quality (All values in mg/l )

O= October; M= March

Sample No.	1	2	3	4	5	6	7	9
pH								
O	7.25	7.1	7.2	7.0	-	7.05	-	7.3
M	7.20	7.4	7.3	7.2	6.8	7.10	7.3	7.4
T.D.S.								
O	459.00	332.0	306.0	281.0	-	791.00	-	383.0
M	326.00	275.0	280.0	291.0	234.0	611.00	840.0	332.0
Total	368.00	268.0	346.0	350.0	-	534.00	-	279.0
Hardness	230.00	203.0	233.0	213.0	187.0	477.00	554.0	280.0
Total	426.00	364.0	463.0	504.0	-	520.00	-	348.0
Alka.	488.00	478.0	462.0	422.0	416.0	378.00	330.0	272.0
Na <sup>+</sup>								
O	39.00	24.5	27.0	38.0	-	86.00	-	41.0
M	75.00	21.0	20.5	30.0	10.5	106.0	350.4	33.0
K <sup>+</sup>								
O	0.725	0.364	0.725	0.364	-	1.46	-	1.09
M	1.600	1.400	0.400	0.400	0.2	1.80	2.4	0.8
SiO <sub>2</sub>								
O	71.0	123.00	100.00	139.00	-	63.00	-	69.00
M	75.0	132.00	115.00	168.00	121.00	79.00	85.00	85.00
Cl <sup>-</sup>								
O	33.0	5.00	17.00	0.00	-	161.00	-	24.00
M	87.0	16.00	29.00	8.00	17.00	32.00	275.00	39.00

trend. Whether the higher values of the cation reflect greater weathering of rocks is not clear from this set of data.

As mentioned earlier the ~~xxx~~ soils, particularly of 'A' horizon, are rich in carbonate concretions. A typical well water ( No. 3) shows ionic activity product  $a_{Ca^{++}} \times a_{CO_3^{=}}$  close to the solubility product of calcite at 25°C as shown below -

$$\begin{aligned} \text{Temp. } & 27^{\circ}\text{C} \\ \text{pH} & 7.2 \\ m_{HCO_3^{-}} & 9.3 \times 10^{-3} \text{ moles/l} \\ a_{HCO_3^{-}} & 0.9 \times 9.3 \times 10^{-3} = 10^{-2.08} \\ a_{CO_3^{=}} & \text{calculated from the second dissociation constant of } H_2CO_3 \\ & (10^{-10.3}) \text{ is equal to } 10^{-5.18} \\ a_{Ca^{++}} & = 10^{-3.45} \\ \text{so, } a_{Ca^{++}} \times a_{CO_3^{=}} & = 10^{-8.63} \end{aligned}$$

This product is slightly less than the theoretical solubility product of calcite ( $10^{-8.35}$ ).

The waters are therefore close to equilibrium with the calcite present in the materials.

An important test of rock-water equilibrium with the ca is defined whether some of the soil- ~~minerals~~ minerals present are thermodynamically stable in the aquatic environment. For this purpose stability diagrams ( fig. No. 11, 12, 13) were drawn after the method of Garrels and Christ (1965) and Tardy ( 1971) for the systems listed below:-

#### K- System

Gibbsite	$Al_2 (OH)_6$
Kaolinite	$Al_2 Si_2 O_5 (OH)_4$
Muscovite	$K_2 Al_3 Si_3 O_{10} (OH)_2$
K- feldspar	$K_2 Al Si_3 O_8$

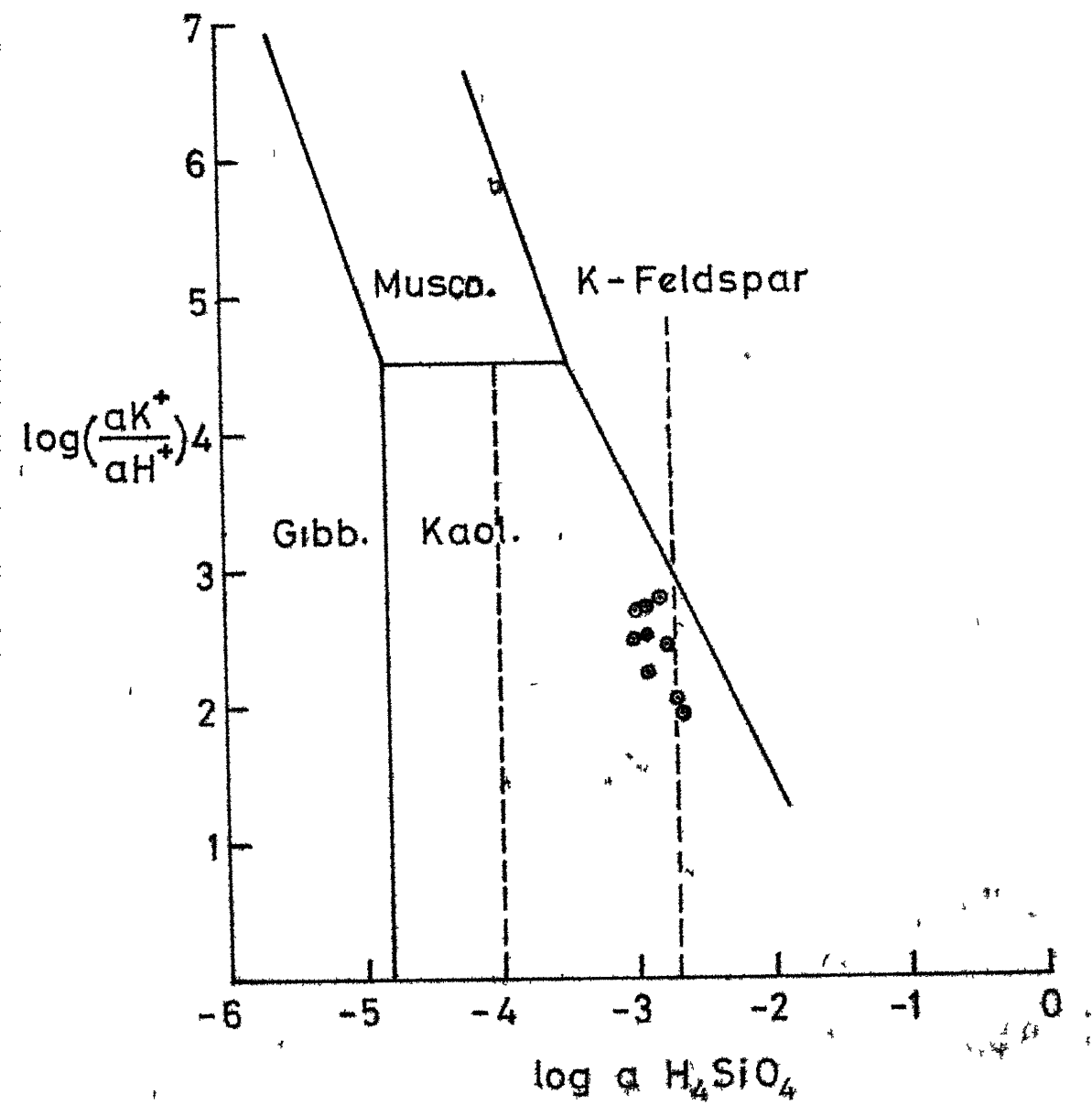


FIG. 11

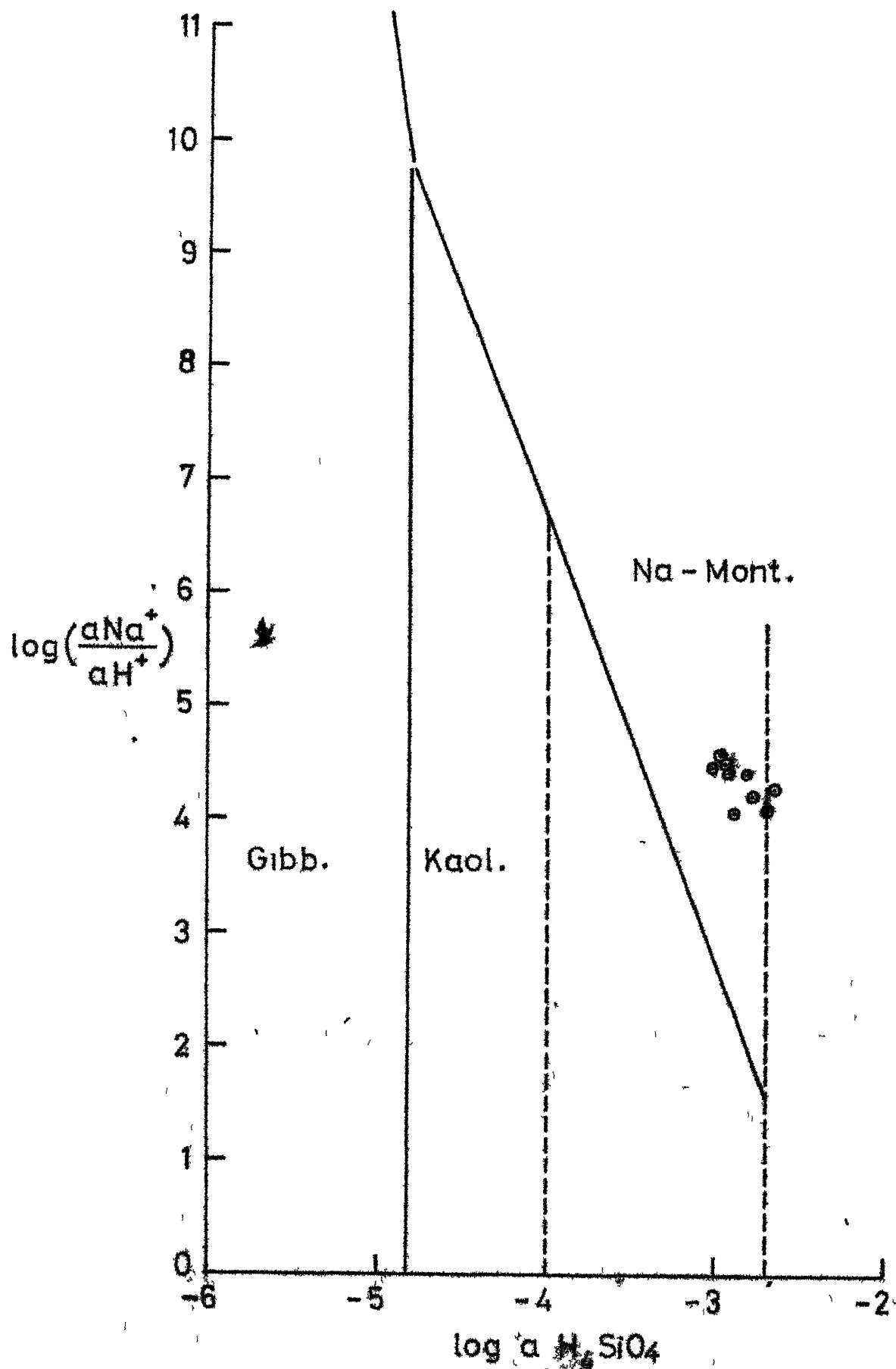


FIG. 12



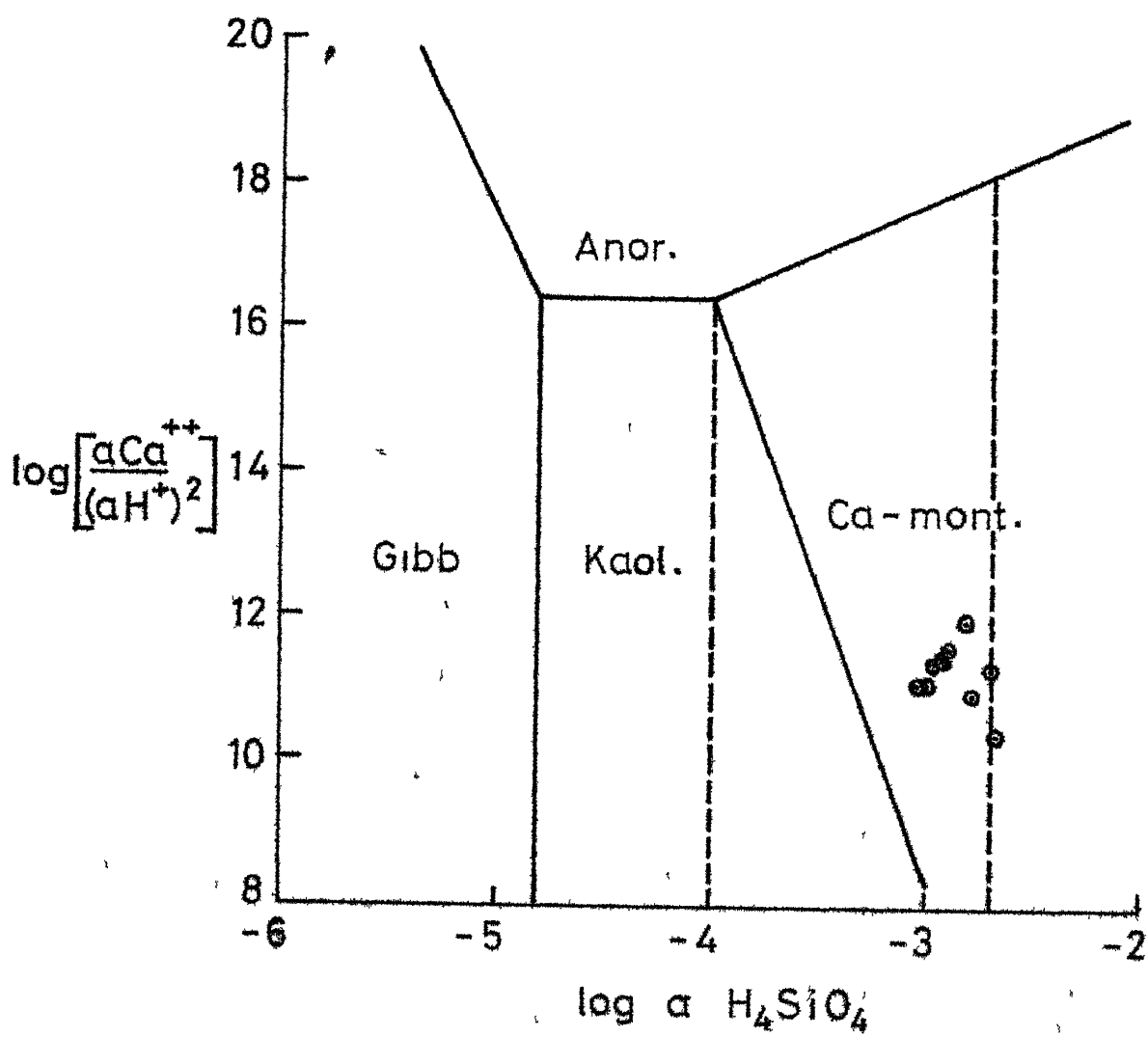


FIG. 13

- (1)  $\text{Kaol.} + 5 \text{H}_2\text{O} = \text{gibb.} + 2\text{H}_4\text{SiO}_4$   
 $\log a_{\text{H}_4\text{SiO}_4} = -4.82$
- (2)  $2 \text{Musco} + 2\text{H}^+ + 3\text{H}_2\text{O} = 3 \text{Kaol.} + 2\text{K}^+$   
 $\log (a_{\text{K}^+} / a_{\text{H}^+}) = 4.52$
- (3)  $2 \text{Musco.} + 2\text{H}^+ + 18 \text{H}_2\text{O} = 3 \text{gibb.} + 2\text{K}^+ + 6 \text{H}_4\text{SiO}_4$   
Slope of the boundary = - 3.1
- (4)  $3 \text{K-felds.} + 2\text{H}^+ + 12\text{H}_2\text{O} = \text{Musco} + 6\text{H}_4\text{SiO}_4 + 2\text{K}^+$   
 $3 \log a_{\text{H}_4\text{SiO}_4} + \log (a_{\text{K}^+} / a_{\text{H}^+}) = -5.93$
- (5)  $2\text{K-felds.} + 2\text{H}^+ + 9\text{H}_2\text{O} = \text{Kaol} + 2\text{K}^+ + 4\text{H}_4\text{SiO}_4$   
Slope of the boundary = - 2.1
- (6) Solubility of quartz (6 ppm  $\text{SiO}_2$ )  
 $\log a_{\text{H}_4\text{SiO}_4} = -4$
- (7) Solubility of amorphous silica (120 ppm  $\text{SiO}_2$ )  
 $\log a_{\text{H}_4\text{SiO}_4} = -2.7$

#### Na-System

Gibbsite

Kaolinite

Na-montmorillonite  $\text{Na}_{0.33} \text{Al}_{2.33} \text{Si}_{3.67} \text{O}_{10} (\text{OH})_2$

- (1)  $6 \text{Na-mont.} + 2\text{H}^+ + 23\text{H}_2\text{O} = 7 \text{Kaol.} + 8 \text{H}_4\text{SiO}_4 + 2 \text{Na}^+$   
 $4 \log a_{\text{H}_4\text{SiO}_4} + \log (a_{\text{Na}^+} / a_{\text{H}^+}) = -9.31$
- (2)  $6 \text{Na-mont.} + 2\text{H}^+ + 58\text{H}_2\text{O} = 7 \text{gibb.} + 22\text{H}_4\text{SiO}_4 + 2\text{Na}^+$   
Slope of the boundary = - 11.1

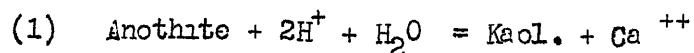
#### Ca-System

Gibb.

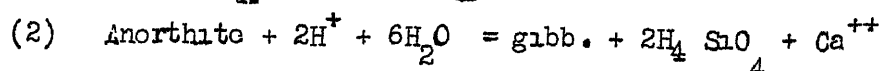
Kaol.

Ca-montmorillonite  $\text{Ca}_{0.17} \text{Al}_{2.34} \text{Si}_{3.66} \text{O}_{10} (\text{OH})_2$

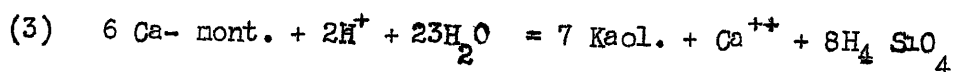
Anorthite  $\text{CaAl}_2\text{Si}_2\text{O}_8$



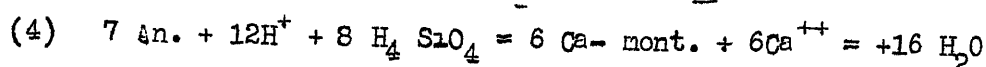
$$\log a[\text{Ca}^{++}/(\text{aH}^+)^2] = 16.41$$



$$\text{Slope of the boundary} = -2 \quad 1$$



$$8 \log a \text{H}_4\text{SiO}_4 + \log a[\text{Ca}^{++}/(\text{aH}^+)^2] = -15.7$$



$$\text{slope of the boundary} = +4 \quad 3$$

The silica level of the waters are above quartz saturation and generally below amorphous silica saturation. Although in the K- system the water composition plots in the kaolinite field, diagrams in Na and Ca systems show that the montmorillonite mineral with exchangeable  $\text{Na}^+$  or  $\text{Ca}^{++}$  is stable in this environment. In these two systems the waters are close to the kaolinite - montmorillonite boundary and it must be pointed out that the exact position of these boundaries depend on the stoichiometric formula of the montmorillonite phase. In other words, inspite of the fact that the waters plot away from this boundary the control of the kaolinite - montmorillonite equilibrium on their composition is not ruled out. These diagrams have been drawn taking idealised Na- montmorillonite and Ca- montmorillonite formulae which may not be the composition of the montmorillonite developed during soil formation. Looking from another point of view, the primary feldspar minerals are unstable in the environment of these ground waters. The water composition seems to have attained equilibrium with montmorillonite mineral which is one of the most important secondary mineral constituting the black soils.

Solubility of volcanic glass ( amorphous silica ) apparently exerts an additional control. It will be worth while to investigate the role of pyroxene and other ferromagnesian minerals in similar rock - water equilibrium systems.

#### 4.3.2 Geochemical Mobility of the Cations

The rate at which individual constituents are removed relative to ~~their~~ abundance in the rock - the relative mobility ( Chapter II ) -- however, may be notably different. Therefore, the mechanism of weathering was also studied in terms of the relative mobilities of the cations. The results obtained for the average Deccan Trap rock and water are given in the following table:

TABLE 11

#### Relative Geochemical Mobility of the Elements

	Average Trap Rock Wt. %	Atomic Percentage(R) Element %	Atomic * Percentage (W) Element %	Ratio W/R	
SiO <sub>2</sub>	50. 61	Si	56. 10	12. 39	0. 203
CaO	9. 45	Ca	9. 93	23. 60	2. 375
MgO	5. 46	Mg	11. 60	35. 10	3. 025
FeO	9. 92				
Fe <sub>2</sub> O <sub>3</sub>	3. 19	Fe	17. 20	0. 35	0. 020
Na <sub>2</sub> O	2. 60	Na	4. 44	28. 20	6.360
K <sub>2</sub> O	0. 72	K	0. 90	0. 33	0. 365
			100. 17	99. 97	
Relative Mobility Na 7 Mg Ca K Si Fe					

\* Average of 9 water samples in Table No. 8

For each element considered, the percentage in the water is divided by the equivalent percentage in the rock. The greater the resulting ratio, the greater the assumed mobility of the element. For each sample, the weight percentage of the elements considered are recalculated (normalized) so that the total for the rock and for the water will each be 100 percent.

As far as K, Si and Fe are concerned, the sequence obtained accords in general with the calculations of Feth et al (1964) for ground waters in granitic rocks of Sierra Nevada and those of Anderson and Hawkes (1958) for surface waters (Chapter II). But it differs from the calculations by the former in whose sequence calcium is placed first and the other elements conform to the order shown above and the calculations by the latter in whose sequence Mg is placed first followed by calcium which in turn is followed by Na. Higher mobility of Na as compared to Mg and Ca in Trap waters can be explained in terms of thermodynamic considerations. Based on the equilibrium diagrams it has been mentioned earlier that the volcanic glass is highly unstable in the environment of these waters and therefore, sodium, which is almost entirely contained in the glass, is also released along with the dissolution of the glass.

Higher mobility of Mg than Ca is consistent with their relative abundance in the rock as well as the dominance of augite over plagioclase, as revealed by its volume in the rock, suggesting faster weathering of augite than plagioclase. However, the possibility of fixation of Ca in soil horizon (in montmorillonite and lime concretion) is also not ruled out.

## CHAPTER V

## CONCLUSIONS

On the basis of the present study the following conclusions have been drawn.

- (1) The country rock of the Malwa Plateau is the typical Deccan basalt . The 5th flow aquifer around Sagar contains augite 49. 5%, plagioclase 21. 6%, glass 20. 5%, palagonite 5.6%, magnetite 2.1%, iddingsite 0.8% and micaceous minerals 0.1 %, by volume.
- (2) The physical properties of the soils indicate two groups (1) the black soils developed on the foot-hills and (2) the " lateritic" reddish -brown soils on the hill-tops and hill-slopes. The first group is characterised by lower specific gravity ( av. 2. 63), low shrinkage limit ( av. 13%), high liquid limit ( av. 75%)and high plasticity index ( av. 41%). According to the unified system of classification this group of soils has been classified as C.L.H. CH-MH

The second group is characterised by high specific gravity (av. 2.85), high shrinkage limit ( av. 21.5 %), low liquid limit (av. 45.2%) and low plasticity index(av. 19.0%). According to the Unified system of classification this group of soils has been classified as CL-ML.

- (3) These differences in the physical properties are the reflection of the mineral content of the soils. The black soils are high in clay content ( 43%), the dominant clay mineral being montmorillonite with traces of illite and kaolinite. The " lateritic " soils have no X- ray detectable clay- minerals although the D.T.A. patterns are similar to those of the black soils. The other minerals identified are ferric oxide, calcite and quartz .

- (4) Samples of well and spring waters from these soil horizons, are near neutral, total dissolved solids are in the range 325- 700 mg/l as  $\text{Ca CO}_3$  , and the bicarbonate alkalinity ranges from 300- to 500 mg/l as  $\text{Ca CO}_3$  . Major cations are  $\text{Ca}^{++}$  ,  $\text{Mg}^{++}$  ,  $\text{Na}^+$  and  $\text{K}^+$  which are balanced by the anions  $\text{HCO}_3^-$  ,  $\text{Cl}^-$  , and  $\text{SO}_4^{--}$  . The average ionic strength of the waters is 0. 012.
- (5) There is no appreciable change in the bulk composition of the waters during 4 months as shown by the analyses of post-monsoon waters in October and pre-monsoon values in March. However, minor differences were observed in the composition, i.e.,  $\text{Na}^+$  ,  $\text{K}^+$  , and  $\text{SiO}_2$  slightly increased and the T.D S., alkalinity and total hardness slightly decreased.
- (6) The waters are close to equilibrium with the calcite present in the soils .
- (7) A plot of water composition on the equilibrium diagrams show that silica concentration is above quartz solubility and generally below amorphous silica saturation suggesting strong control of dissolution of volcanic glass on water quality . The same is true for the primary feldspar minerals also, which are unstable in the environment of ground waters.
- (8) It is obvious from the equilibrium diagrams that the waters have attained equilibrium with kaolinite montmorillonite and the latter is the stable mineral in this environment.

- (9) The higher geochemical mobility of Na which is contained in bulk with in the glass, can be explained in term of the thermodynamic unstability of the latter ( para 7 above). The greater mobility of Mg than Ca is consistent with the relative abundance of the former in the rock as well as dominance of augite over plagioclase. The smaller relative mobility of calcium than magnesium and sodium can be due, probably, to the formation of lime concretions and Ca- montmorillonite resulting in its fixation in the soil profile.
- (10) The following relative rate of weathering of three major constituent of the t Trap rock can be deduced.

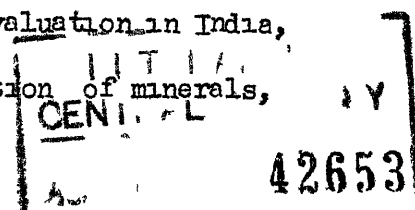
Glass > Augite ~ Plagioclase



REFERENCES

- Banerjee, S.P. ( 1970 ) : A pedological characterisation of the black soils on Trappean rocks of Indore, Jr. Soil. Wat. Conserv. Ind., 18 ( 1 & 2 ), 30- 38.
- Black, W. Hanshaw, B B and Rubmn , M.,(1967) : Field study of carbonate Kinetics, U.S G.S., Professional Paper, 575-A, P. A162.
- Bose, M.K. ( 1972 ): Deccan basalts, Lithos 5 , 131- 145.
- Chatterjee, S.C. ( 1964 ) : Petrochemistry of the lavas of Pavagad Hill, Gujrat, Adv. front. Geol. Geophys., 385- 397.
- Crookshank, H. ( 1936 ) Geology of the northern slopes of the Satpuras between Morend and Sher rivers, Mem. Geol. Surv. Ind. 66 (2).
- Deshmukh, D.S. and Karanth, K P. ( 1973 ) Chemical quality of ground water in South India, Proc. Int. Symp. on Gr. Wat. Resources, 3 , VI.1- VI. 8.
- Dharanendran, S P and Nagaraja, G.H. ( 1969 ) . Water quality requirements for various purposes with notes on quality of water from different districts in Mysore state, Rep. Gr. Wat. Studies, No. 22, Deptt. Mines and Gology, Mysore.
- Feth, J.H , Roberson, C E. and Polzer, W L., (1964 ) . Sour ces of mineral coustituents in Water from granitic rocks, Siorra Nevada, California and Nevada, U.S G S. Water Sypply Paper, ~ 1535 - 1 .
- Gananathan, V.S , ( 1967 ) . Economic Geography of India, Chap. I, 8-10, National Book Trust, India.
- Garrels, R.M. and Christ, C L., (1965): Solutions, Minerals and Equilibria, Harper and Row, New York .

- Gidigas, M.D., (1974) : Degree of weathering in the identification of lateritic materials for engineering purposes - A review, Engg. Geol. 8 , 213-266.
- Grim, R.E., ( 1968 ) : Clay Mineralogy, Chap. 13, 479- 574, Mc Grow- Hill.
- Harris, R C. and Adams, J.A.S (1966): Geochemical and mineralogical studies on the weathering of granitic rocks, Amer. Jr. Sci., 264 , 146-173 .
- Katti, R K., ( 1966 ) Research on black cotton soils with and without inorganic additives, Road Research Bulletin, No. 10, Indian Road Congress.
- Krishnan, M.S. ( 1926 ). Petrography of rocks from the Garhar and Osham Hills, Kathiawar, Rec. Geol. Surv. Ind. 58, 380- 424.
- Le Grand, H E. ( 1958 ) . Econ. Geol., 53, 178- 89 .
- Lohnes, R A., and Demmel, T., ( 1973 ): Strength and structure of laterites and lateritic soils, Engg. Geol., 7 , 13-33.
- Lunkad, S.K., ( 1971 ): Geology of the area around Titarpam, Rehlh Tahsil, Sagar District, Chap. 3, p.47, M. Tech . dissertation submitted to the University of Saugar, M P.
- Mathur, K K. et al ( 1926 ) . Magmatic differentiation in the Garhar Hills, Jour. Geol. 34, 298- 307.
- Miller, W.J. ( 1948 ) . An introduction to physical geology, Chap. 7, 157-184, Van Nostrand and East- West Press, New Delhi .
- Mitchell, W.A., ( 1955 ). A review of the mineralogy of Scottish soil clays, Jr. Soil. Sci., 6 (1), 94-98.
- Raymahashay, B.C. and Yudhbir ( 1973 ) : Remote sensing and geochemical techniques in ground water quantity and quality evaluation in India, Indo Soviet Symposium on recent trends in exploration of minerals,



- oil and ground water ( New Delhi ).
- Simonson, Roy W., ( 1954). Morphology and classification of the regur  
soils of India, Jr. Soil. Sci., 5 (2), 275- 288.
- Singh, S. ( 1954). A study of the black cotton soils with special  
reference to their coloration, Jr. Soil. Sci., 5 (2), 289 -299.
- Singhal, B.B.S., ( 1973): Some observations on the occurrence, utilization  
and management of ground water in the Deccan Trap areas, central Maharas-  
htra, India, Proc. Int. Sump. on Development of Gr. Wat. Resources  
( Guindy, Madras) 3 , V 75- V 81.
- Skempton, A.W., ( 1953) The Colloidal activity of clays, Proc. 3rd  
Inter. Conf. Soil. Mech. Found. Eng. ( Switzerland), 1 , 57.
- Subramanyan, V. ( 1973): Geomorphology of the area around Sagar, M.P.,  
Ph.D. thesis submitted to the University of Sagar, M.P., 48-52.
- Sukheswal, R.N. and Poldervaart, A., ( 1958): Deccan basalts of the  
Bombay area, Bull. Geol. Soc. Amer. 69 , 1475-1494.
- Tracy, Y., ( 1971) Characterization of the principal weathering types by  
the geochemistry of waters from some European and African Crystalline  
massifs, Chem. Geol., 7 , 253 - 271.
- Tyagi, K.S , ( 1973): Soil Cement interaction, Ind. Geotech. Jr., 3 (4),  
307- 313.
- 
- Valotou , Ida, ( 1972) : Bauxites, Elsevier, New York,  
U.S.A.
- Wadia, D. N., ( 1966): Geology of India, Chap. XVI, 292 - 304, E.L.B.S &  
Macmillan & Co., London.

Washington, H.S. ( 1922): Deccan Traps and other plateau basalts, Bull.

Geol. Soc. Amer. 33 , 765- 804.

West, W.D., ( 1958): The petrography and petrogenesis of 48 flows of

Deccan traps penetrated by borings in Western India., Trans. Nat.

Instt. Sci. Ind. 4 ( 1 ), 1-56.